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An Easier Way to a Harder Spectrum: Generating a Fast Neutron Flux Spectrum in a Mark II TRIGA Reactor Using a Uranium-Boron-Cadmium Converter

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An Easier Way to a Harder Spectrum: Generating a Fast Neutron Flux Spectrum in a Mark II TRIGA Reactor Using a Uranium-Boron-Cadmium Converter

by

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Report

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December 2019

Acknowledgements

There are many people that I would like to thank for my time at the University of Texas. First, thank you to all the faculty members of the Nuclear and Radiation Engineering Program at the University of Texas. This program has been incredibly rewarding, and I have learned so much from all of you. Thank you, especially, for opening your classes to distance students like me. I understand how difficult it must be to teach to students who are not physically present at the campus, and I sincerely thank you for your patience and understanding with those of us who are unable to be in Austin full-time.

In particular, thank you to my adviser, William Charlton, who guided me through this project as well as previous courses. Thank you for responding to my numerous emails and for taking phone calls after hours, which was apparently the only time we were both free. I have learned quite a lot from our conversations, and I cannot thank you enough. Thank you also to Kevin Clarno, who agreed to serve as a reader for this report.

I would also like to thank my wife, Jadzia, for her love and support. Thank you for putting up with my decision to go to school part-time and for patiently pretending to listen as I tried to explain what I was working on over the past few years. You are an incredible attorney with an unwavering work ethic, and you are a constant inspiration to me. Finally, to our two Labrador retrievers, Gunner and Austin, thank you for bringing a smile to my face every time I came home and for reminding me to take occasional study breaks, usually by knocking my laptop out of my hands.

Abstract

An Easier Way to a Harder Spectrum: Generating a Fast Neutron Flux Spectrum in a Mark II TRIGA Reactor Using a Uranium-Boron-Cadmium Converter

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The TRIGA Mark II research reactor has a flux spectrum with a predominance of thermal neutrons. While most research can be conducted using this thermal neutron flux, an exclusively fast neutron flux is preferred for some experiments, such as radiation damage studies. Although fast neutron flux spectrums are available using fast reactors or neutron generators, only a few fast reactors are currently in operation and neutron generators tend to have low fluxes. As a result, this report evaluated the possibility of generating a fast neutron flux spectrum in a thermal reactor through the use of an irradiator consisting of layers of uranium, boron, and cadmium. Simulations using Monte Carlo N-Particle Code (MCNP) determined that thin layers of these materials in an irradiator inserted into the 3-Element Facility of the UT-Austin TRIGA reactor will generate a fast neutron flux spectrum with negligible thermal flux and where over 91% of the total flux consists of neutrons with energy greater than 10 keV. Further research is recommended to calculate heat dissipation and to determine the reactivity worth of the irradiator.

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Chapter 1: Introduction and Project Motivation

The TRIGA Mark II reactor at the Nuclear Engineering Teaching Laboratory (NETL) at the University of Texas at Austin (UT-Austin) provides students and staff with multiple irradiation locations that allow for a wide variety of research beneficial to academia, industry, and government [26]. Like all TRIGA reactors, the NETL reactor is a "thermal" reactor, meaning that low-energy neutrons called "thermal neutrons" are predominantly responsible for causing fission and sustaining the reactor's chain reaction. As a result, a significant percentage of the neutron flux in TRIGA reactors consists of thermal neutrons [1]. While this thermal neutron flux is useful for many experiments, certain experiments such as fast neutron damage studies or fast neutron cross-section calculations require a neutron flux spectrum composed almost exclusively of high energy, "fast" neutrons—that is, a flux spectrum similar to the spectrum produced directly from fission [15, 28].

Fast neutron spectrums may be generated using fast neutron nuclear reactors or standalone neutron generators. Unfortunately, only five fast neutron nuclear reactors are currently in operation throughout the world, and those reactors are located in Russia, China, and India [10]. Additionally, while standalone (i.e., non-reactor) neutron generators can be used to create a fast neutron spectrum, these generators are expensive, difficult to operate, and often have low neutron fluxes [8, 23]. Given the large number of thermal reactors, including 66 TRIGA reactors currently operating in 24 different countries, it would be preferable if the flux in a thermal reactor could be converted to a fast neutron flux spectrum, at least at the point where research or sampling is conducted [26]. Such a system would enable experiments and testing that require a purely fast neutron flux spectrum to be accomplished using already installed and widely available systems.

Several thermal reactor research facilities have produced a fast neutron flux spectrum in a thermal reactor using absorber materials to remove the thermal neutron flux to produce a “harder” spectrum, but these irradiators decreased the overall neutron flux delivered to the sample [5, 7, 24]. Ideally, an irradiator could be designed to both filter out the thermal neutron flux while also using fission to convert some of those thermal neutrons to fast neutrons, thereby increasing the fast flux measured at the sample location and resulting in a harder overall spectrum. Our research hypothesized that a converter that utilized both uranium and an absorber material might provide the desired spectrum. We hypothesized that the uranium would absorb some thermal neutrons, fission, and produce fast neutrons in the immediate vicinity of the sample while the absorber material would remove any remaining thermal neutrons before those neutrons reached the sample. The research presented in this report is limited to conducting Monte Carlo N-Particle (MCNP) analysis to evaluate the feasibility of creating such a converter.

Chapter 2 provides background information on neutron speeds, production of neutrons from fission, and explains why the flux in a thermal reactor consists predominantly of thermal neutrons. Chapter 2 also provides a brief explanation of uranium enrichment and provides the criteria we used to evaluate our proposed designs.

Chapter 3 discusses the results obtained from attempting to use the TRIGA reactor’s pneumatic transport tube system to generate the desired spectrum. The pneumatic transport tube system consists of a series of small, aluminum tubes that transfer samples from the reactor's laboratory into the core of the reactor and back for measurement. Because the system is already installed and is already used to test samples using the reactor's flux, it would be an ideal location for such a converter. However, as discussed in Chapter 3, although the proposed modifications to the pneumatic transport tube system did increase the fast flux in the vicinity of the sample location, the thermal flux was not reduced sufficiently to meet the criteria established in Chapter 2.

Given that use of the pneumatic transport tube system did not meet our required criteria, Chapter 4 discusses the results obtained using the TRIGA reactor's 3-Element (3-L) Facility. The 3-L Facility is a location in the reactor core where three elements are not filled with either a control rod or a fuel rod and where an irradiator can be inserted for in-core testing. As Chapter 4 discusses, various iterations of materials that could be placed in the irradiator in the 3-L Facility were attempted until a combination of uranium, boron, and cadmium was determined to provide the best results for maximizing the fast neutron flux while minimizing thermal flux. The dimensions of each component were then varied to find an optimal combination that met the criteria established in Chapter 2.

Chapter 5 presents the final results of this research. Utilizing the optimal configuration discovered in Chapter 4, Chapter 5 presents the results of MCNP analysis using more detailed energy groupings that provide greater fidelity of the flux spectrum that would be present at the sample location. The results of our MCNP analysis show that the designed converter produces a flux spectrum very similar to the flux spectrum produced directly from the fission of U-235, indicating that the converter successfully produced neutrons from fission near the sample location while also absorbing thermal neutrons before those neutrons reached the sample location.

Finally, Chapter 6 discusses future work, including research to ensure sufficient heat transfer from the system, research to determine the reactivity worth of the converter and burn out of converter material over long-term usage, and finally building a prototype to test these results. If the prototype is successful, this converter design may allow fast-spectrum testing in a thermal reactor without significant modification to normal reactor operations.

Chapter 2: Background

2.1 Neutron Speeds

Neutrons are loosely classified into different categories based on their energy or speed, where the terms “energy” and “speed” are interchangeable because a neutron’s kinetic energy is directly related to its velocity. Although various categorizing systems and names are present in the literature, three classifications of neutron energy are commonly used: thermal, epithermal, and fast. These categories provide useful terminology for quickly and easily describing a neutron spectrum.

The term “thermal neutron” refers to neutrons that are in equilibrium (or at least very close to equilibrium) with the thermal motion of the surrounding materials—that is, the kinetic energy of the neutrons is largely, or almost completely, due to the temperature of the surrounding material [14]. At such a low energy level, neutrons can both lose energy (“down scatter”) and gain energy (“up scatter”) from collisions with the surrounding material [14]. Because neutrons can both down scatter and up scatter, neutron energies at these low levels are characterized by a Maxwell-Boltzmann distribution with a mean energy that depends on the temperature of the material; at room temperature, this equates to a mean energy of approximately 0.025 eV and a most probable velocity of 2200 m/s [16, 17]. Because this range of energies depends on the temperature of the surrounding materials, stablishing a cutoff energy for “thermal neutrons” is not perfectly clear. In many cases, however, thermal neutron energies are defined by the means with which they are measured—typically by using a cadmium cover on a dosimetry foil. Because cadmium absorbs almost all neutrons with energies less than 0.7 eV, thermal neutrons are often defined as those neutrons with energies less than 0.7 eV (see Figure 3.2 and discussion, *supra*) [2, 16].

Although many classification systems state that any neutron that is not thermal is "fast," some classification systems include an intermediate category of neutron energy, and neutrons in this category are often referred to as "epithermal neutrons" or "resonance neutrons." Epithermal neutrons may be defined as neutrons in which "the kinetic energy distribution . . . exceeds that of the thermal movement" [21] or as "[n]eutrons of kinetic energy greater than that of thermal agitation" [6, 21]. Given these generic definitions, it is not surprising that energy ranges for epithermal neutrons also vary greatly. Different sources list epithermal neutrons as having energy ranges of 1 eV to 1 keV, 0.5 eV to 100 keV, and 0.025 eV to "a few hundred eV" [2, 12, 22]. Regardless of the exact definition, these neutrons are usually above the energy level at which the temperature of the surrounding medium affects neutron energy, and these neutrons are unlikely to up scatter as a result of interactions with the surrounding material.

Finally, there are "fast neutrons." Fast neutrons are neutrons of higher energy, and the term generally refers to neutrons released as part of a nuclear reaction such as fission. Again, there is no exact definition for energy ranges that clearly define a neutron as fast, but some typically cited energy ranges for fast neutrons include greater than 1 MeV or generally between 0.1 and 10-20 MeV [19, 31].

2.2 Neutrons are Born Fast

Importantly, neutrons released from a fission reaction are fast neutrons, and although spontaneous fission neutrons, (α,n) neutrons, (γ,n) neutrons exist in a nuclear reactor, the primary source of neutrons in any thermal reactor are the fast neutrons produced from fission of U-235.

The majority of fission reactions occur when U-235 absorbs a neutron, becomes unstable, and fissions into two fission fragments, several gammas, and several (two to three) prompt neutrons. Equation (1) shows a typical reaction for U-235 fission where two prompt neutrons are released.

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow ({}^{236}_{92}U)^{*} \rightarrow F_1 + F_2 + {}^{0}_{0}\gamma' s + 2\,{}^{1}_{0}n \tag{1} $$

In Equation (1), F_1 and F_2 are two new isotopes called fission fragments. The exact isotopes that are produced differ with each fission but are distributed asymmetrically with one isotope usually being heavier (atomic mass around 135 to 145) and one isotope usually being lighter (atomic mass around 90-100), depending on the energy of the incoming neutron [14]. Figure 2.1 shows the distribution of fission fragments by mass number for fission of U-235.

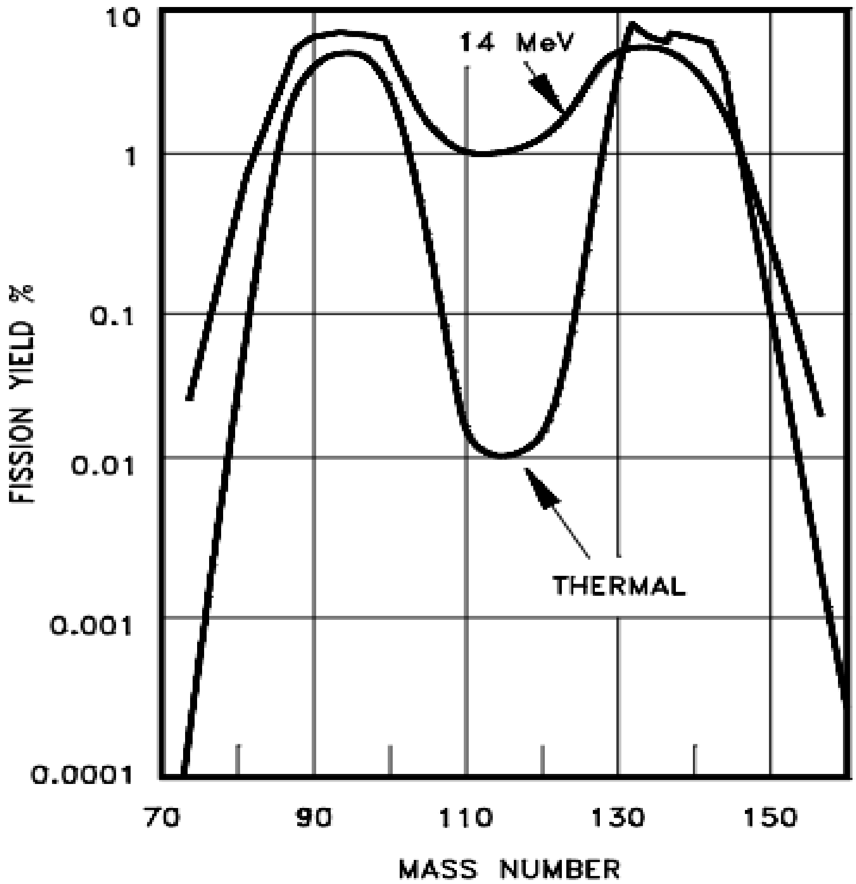

Figure 2.1: Uranium-235 Fission Yield vs. Mass Number [31].

Although the two fission fragments split the 92 protons that were originally in the U-235 nucleus, the fission fragments cannot absorb all of the 144 neutrons (143 neutrons in U-235 plus the neutron absorbed to cause the fission). Compared to lighter nuclei with fewer protons, heavy isotopes like U-235 require a larger ratio of neutrons to protons. This larger number of neutrons is required to exert the strong nuclear force needed to counteract the electromagnetic forces pushing the positively charged protons (and the nucleus) apart. Because the fission fragments produced from fission are lighter nuclei than U-235, a lower neutron to proton ratio is required to achieve a stable or semi-stable configuration, and as a result, approximately two to three excess neutrons are released. These neutrons are referred to as “prompt” neutrons because they are released from the fission reaction immediately, whereas “delayed” neutrons are neutrons resulting from fission that are released by radioactive decay of the fission fragments at a slightly later time. For U-235, the average number of prompt neutrons released per fission is 2.418 [17]. Delayed neutrons constitute less than one percent of the neutrons attributable to the fission process, and almost no delayed neutrons are classified as fast neutrons.

Each fission of a U-235 atom releases close to 210 MeV, of which approximately 200 MeV is recoverable through heat and about 187 MeV of which is released immediately. As Figure 2.2 shows, over 80% of that energy goes to the kinetic energy fission fragments, and the rest of the energy is divided up among the other particles that are released, including the prompt neutrons.

TABLE 6 Instantaneous Energy from Fission	
Kinetic Energy of Fission Products	167 Mev
Energy of Fission Neutrons	5 MeV
Instantaneous Gamma-ray Energy	5 MeV
Capture Gamma-ray Energy	10 MeV
Total Instantaneous Energy	187 MeV

TABLE 7 Delayed Energy from Fission	
Beta Particles From Fission Products	7 Mev
Gamma-rays from Fission Products	6 MeV
Neutrinos	10 MeV
Total Delayed Energy	23 MeV

Figure 2.2: Energy Release from Fission of U-235 [31].

Approximately 5 MeV of kinetic energy is shared among the two to three prompt neutrons that are released. The prompt neutrons do not equally divide up the 5 MeV of kinetic energy they are allocated by the fission process. Instead, prompt neutrons are released with a range of different possible energies, and the probability of a prompt neutron having a certain energy is characterized by the Watt's Fission Spectrum [16]. The fraction of fission neutrons produced at a certain energy can be calculated using Equation (2) [16], and a plot of the fission spectrum is shown in Figure 2.3.

$$\chi(E) = 0.453e^{-1.036E} \sinh\sqrt{2.29E} \quad (2)$$

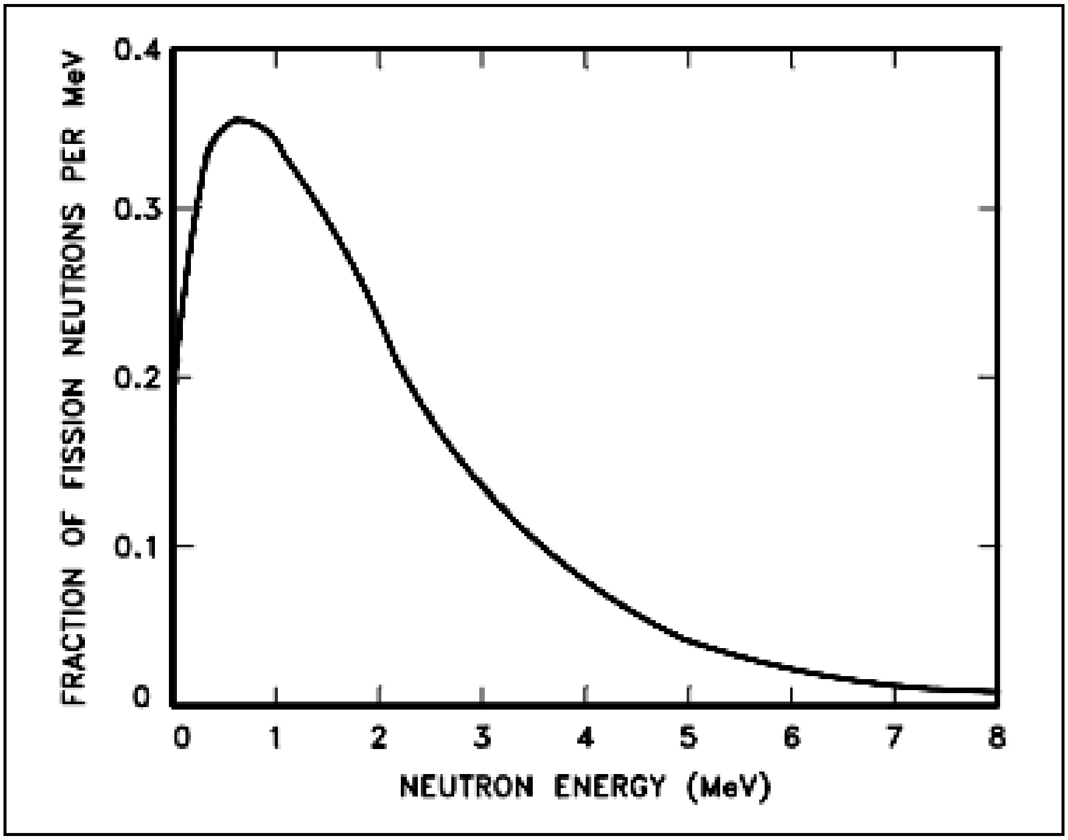

Figure 2.3: Prompt Fission Energy Spectrum for Thermal Fission of U-235 [31].

Using Equation (2), the average energy of a prompt neutron is about 1.98 MeV, and the most probable energy (corresponding to the peak of the function), is approximately 0.73 MeV [16, 17]. Because almost all neutrons produced from fission have energies between 0.1 MeV and 10 MeV, virtually all neutrons born from fission are born as fast neutrons [14, 31].

2.3 But They Don't Stay Fast

Neutrons may be born fast, but they do not stay fast for long. As soon as neutrons are born from fission, they begin interacting with the surrounding material in the reactor in various ways. These interactions are usually classified into two broad categories—scattering reactions and absorption reactions. Scattering reactions may be elastic or inelastic and involve a collision between the incident neutron and a target nucleus that usually results in the incident neutron transferring a portion of its kinetic energy to the target nucleus. In contrast, absorption reactions occur when the incident neutron is fully absorbed into the target nucleus, usually exciting the target nucleus and causing that nucleus to emit other nuclear particles. Fission, for example, is a type of absorption reaction. During fission, the incident neutron is absorbed into the U-235 nucleus, the nucleus becomes excited, and the nucleus undergoes fission and emits numerous nuclear particles, as discussed above.

Each reaction can be characterized by a probability of interaction between the incident neutron and the target nucleus. The probability of a particular reaction occurring per unit distance the neutron travels per unit atom density is called the microscopic cross section (σ) for that reaction. The microscopic cross section is highly dependent on the target nucleus (i.e., what nuclide) as well as the energy of the incident neutron and can be thought of as the "effective area the nucleus presents to the neutron for the particular reaction" [31]. A higher microscopic cross section for a given nuclide and an incident neutron energy means that the reaction is more likely to occur. In nuclear data, microscopic cross sections are often listed by reaction (e.g., scattering, absorption, etc.), to include the total microscopic cross section—that is, the probability of *any* interaction between the nuclide and the incident neutron. For example, for each nuclide and incident neutron energy combination, there are separate cross sections for scattering (σ_s) and absorption (σ_a), and these cross sections can be added together to provide total microscopic cross section ($\sigma_t = \sigma_s + \sigma_a$). The units for microscopic cross section are units of area—centimeters squared. However, because a square centimeter is a large target for a neutron, microscopic cross sections are commonly expressed in terms of barns, where 1 barn is equal to 10^{-24} cm^2.

Understanding neutron cross sections is vital to understanding why neutrons born from fission are fast neutrons but do not remain fast for long. Although it is certainly possible for U-235 to fission after absorbing a fast neutron, thermal reactors rely on thermal neutrons to drive the chain reaction because the microscopic cross section for fission in U-235 for fast neutrons is extremely small compared to the microscopic cross section for fission in U-235 for thermal neutrons. As Figure 2.4 shows, the microscopic cross section for fission for U-235 is orders of magnitude higher for thermal neutrons as compared to the microscopic cross section for fission for fast neutrons. In other words, a thermal neutron is much more likely to cause fission in U-235 than a fast neutron.

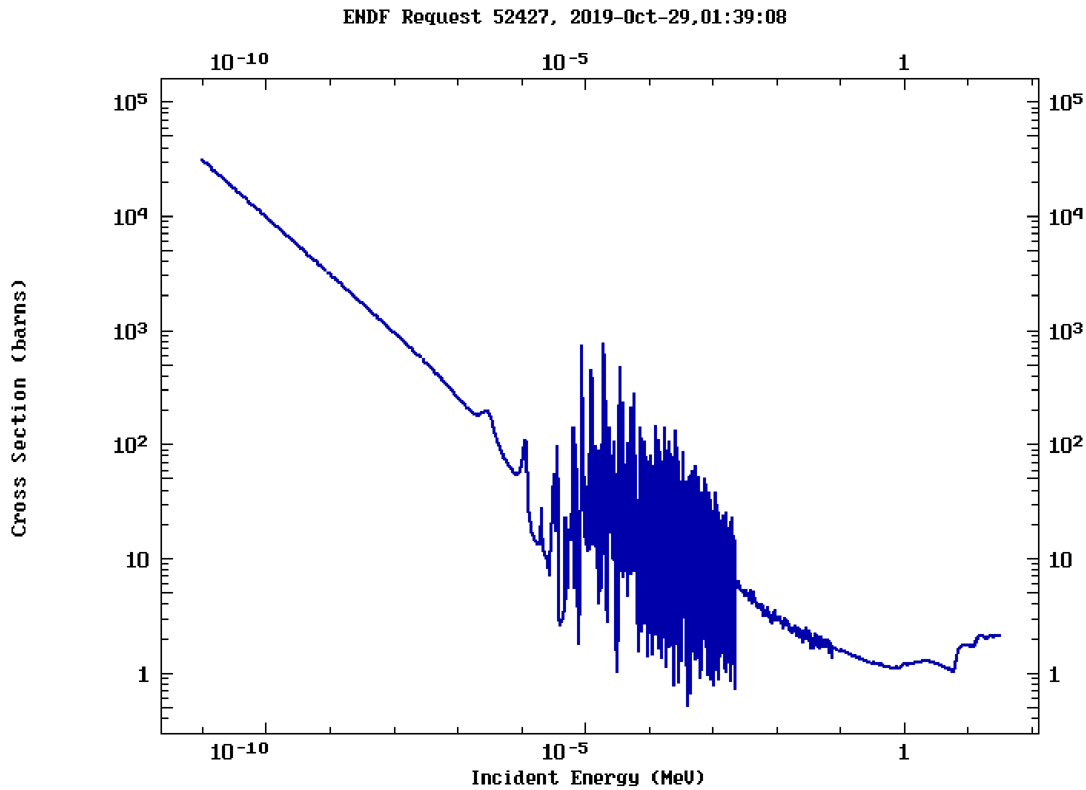

Figure 2.4: IAEA ENDF Microscopic Cross Section for Fission Plot of U-235 [9].

For this reason, thermal reactors are intentionally designed to slow down the fast neutrons born from fission to thermal energies through the use of a "moderator." Typical moderators include water or graphite—materials with low neutron absorption cross sections (will not absorb neutrons that could be used for fission) and small mass (results in greater energy loss per collision compared to heavier nuclides). Designing a nuclear reactor with large amounts of water or graphite to slow neutrons down means that, although neutrons are born fast, they do not stay fast for very long. Through frequent scattering collisions with water or graphite, most neutrons born from fission are quickly moderated to thermal energies (although they might also be absorbed by other materials in the reactor core or might leak out of the reactor entirely).

The result of this design is a neutron flux in a thermal reactor with three distinct components. First, there is a large flux component in the fast energy range that roughly corresponds to the prompt fission spectrum seen in Figure 2.3. Second, there is a smaller flux component spread across the epithermal energy range comprising neutrons that are in the process of slowing down to thermal energies through interactions with materials in the reactor core (although these neutrons may also leak out of the reactor core or be absorbed by other materials in the core while they are slowing down). Finally, another very large flux component—sometimes larger than the fast flux component—exists in the range of thermal energies. Neutrons in this range already have been moderated to thermal energies by interactions with the moderator or other materials in the reactor core. These neutrons will stay in this energy range until they either leak out of the reactor or are absorbed by U-235 or some other material. Although thermal neutrons may up scatter in energy, they will not up scatter out of the thermal energy range. For this reason, and despite the fact that neutrons produced from fission are fast neutrons, the neutron flux spectrum in a thermal reactor is heavily weighted towards the thermal flux side of the spectrum.

Two examples are informative. Figure 2.5 shows neutron flux in the central thimble of a TRIGA reactor—that is, in the very center channel of the TRIGA reactor core.

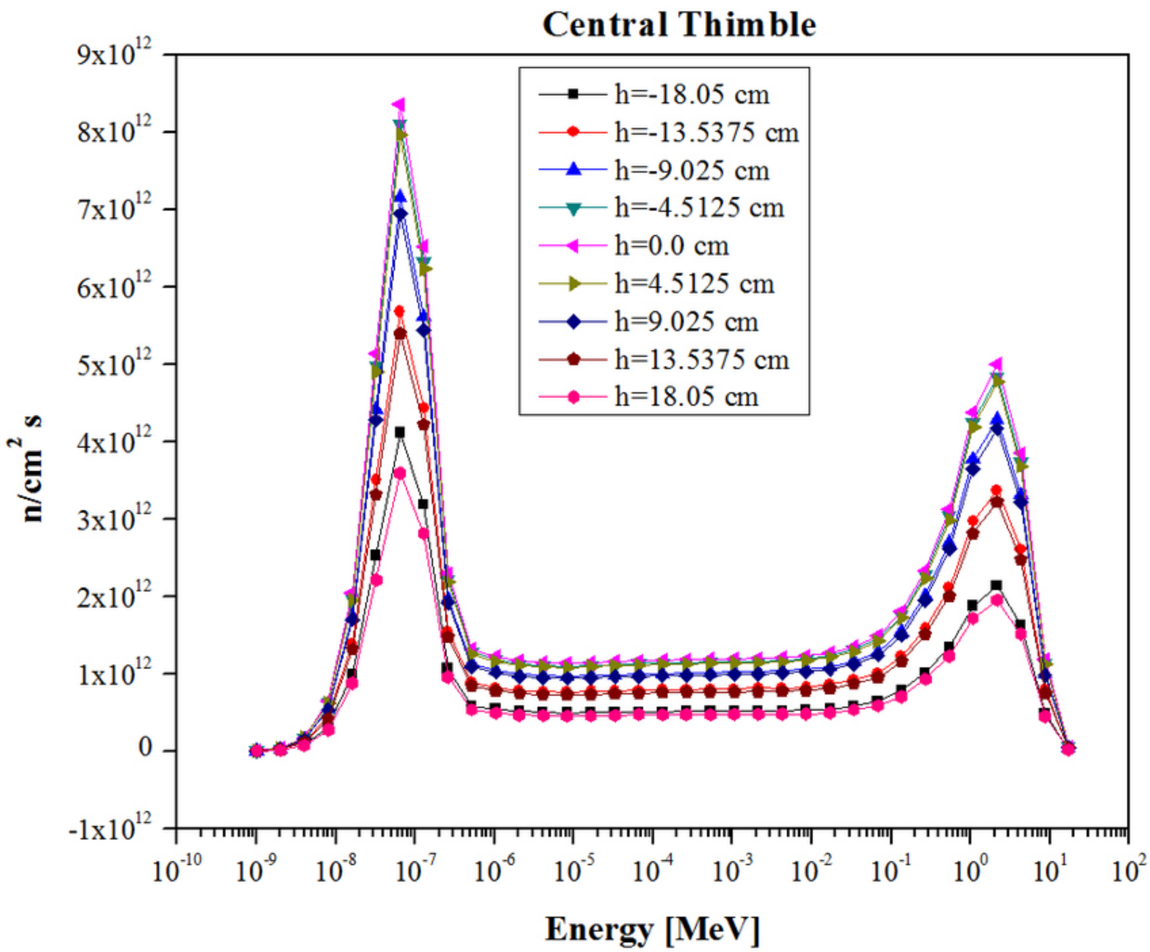

Figure 2.5: Neutron Flux Spectrum in a TRIGA Reactor Central Thimble [3].

Figure 2.5 clearly shows the three distinct components discussed above. The large peak on the left side of the graph is the thermal flux, the flat portion in the middle of the graph is the epithermal flux, and the large peak on the right side of the graph is the fast flux. As can be seen, in the central thimble of this TRIGA reactor, the thermal flux is higher than the fast flux at all heights within the reactor core.

Although a full discussion of fast reactors is beyond the scope of this paper, it is important to recognize that fast reactors are not designed in the same manner as thermal reactors. Rather than intentionally slowing down neutrons to thermal energies using a moderator, fast reactors minimize neutron moderation in order to maintain the fast neutron flux spectrum produced from fission to the maximum extent possible. A comparison of the flux spectra for thermal and fast reactors is shown in Figure 2.6.

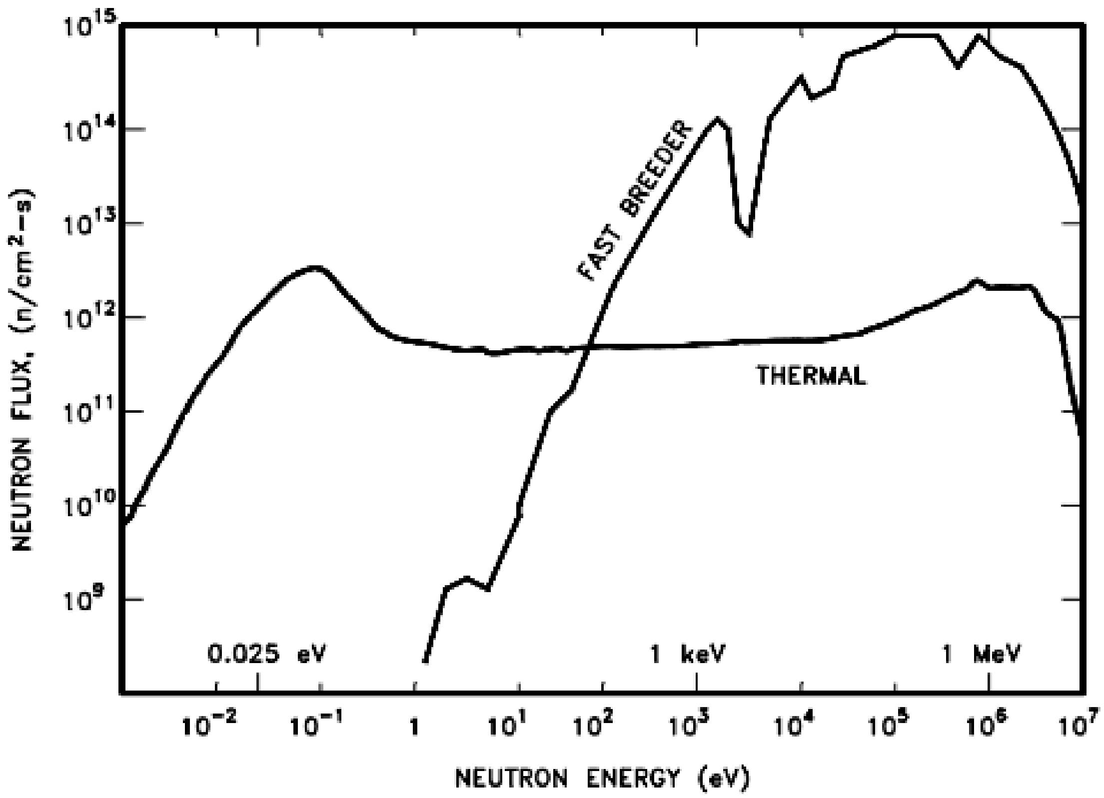

Figure 2.6: Comparison of Neutron Flux Spectra for Thermal and Fast Breeder Reactor [31].

In both fast and thermal reactors, neutrons are born at the same energy—that is, they are born fast. The difference between the above spectra is caused solely by reactor design. Because the TRIGA reactor is a thermal reactor, a large component of the total flux is thermal. As a result, the TRIGA reactor's neutron flux cannot be used for experiments requiring a purely fast neutron flux spectrum without modification—the goal of this project.

2.4 A Brief Note on Enrichment

Natural uranium consists of three naturally occurring isotopes: U-234, U-235, and U-238 (although U-234's abundance is so small (0.0055%) that it is usually ignored when discussing enrichment) [31]. U-235 comprises only 0.72% of natural uranium but is fissile, meaning that fission of U-235 is possible when a U-235 nucleus absorbs a neutron of any energy, including thermal neutrons [14, 31]. U-238 comprises almost 99.2745% of natural uranium, but U-238 is not fissile like U-235 and is instead fissionable, meaning that it will fission but only if it absorbs a neutron above a certain threshold energy (i.e., U-238 will not fission when it absorbs a thermal neutron) [14, 31]. Because U-238 is only fissionable, thermal reactors largely rely on fission of U-235, not U-238, to sustain the chain reaction. However, the extremely small concentration of U-235 in natural uranium is not sufficient to sustain a chain reaction, and as a result, the concentration of U-235 in nuclear fuel must be increased at the expense of U-238 through a process called enrichment.

U-235 concentrations are typically referenced by weight percent U-235. For example, 20% enriched uranium refers to uranium where 20% of the uranium, by weight, is U-235. Typical thermal reactors require uranium enriched to about 2% to 4% U-235, while nuclear weapons require much higher levels of enrichment, typically 90% or more. Importantly, the International Atomic Energy Agency (IAEA) considers uranium enriched to 20% or more to be “highly enriched uranium,” which triggers enhanced security and administrative requirements [19].

In addition to the enhanced security and administrative requirements, highly enriched uranium is much more expensive than natural or low enriched uranium. Because U-235 and U-238 are isotopes, they cannot be separated chemically. Instead, U-235 and U-238 must be separated physically, utilizing the extremely small weight difference between the two isotopes. For most enrichment processes, gas diffusion or gas centrifuges are used repeatedly to slowly increase the concentration of U-235 while slowly decreasing the concentration of U-238. Every increase in U-235 concentration requires additional separative effort, costing money in the form of the facilities and energy used to drive the gas diffusion or centrifuge processes.

2.5 Criteria for a Successful Design

Before discussing the design process, it is important to set out the criteria for a successful design. To be able to quickly and easily compare different simulation results, neutrons were divided into three energy categories—fast, epithermal, and thermal—as shown in Table 2.1. In addition to providing a structure for discussing the benefits and drawbacks of each simulation, these categories were used to establish energy bins in MCNP for initial simulation testing. The larger energy bins provide generally acceptable error rates with sufficient fidelity for comparing different designs, and as will be discussed in Chapter 5, these energy bins were replaced with more detailed energy bins to provide a more comprehensive neutron flux spectrum for the final solution.

Category	Lower Energy Bound (MeV)	Upper Energy Bound (MeV)
Thermal	0.0	0.7 X 10^{-6}
Epithermal	0.7 X 10^{-6}	10 X 10^{-3}
Fast	10 X 10^{-3}	20

Table 2.1: Neutron Categories.

The upper energy bound for the thermal group was chosen to match the cadmium cutoff energy of 0.7 eV. The upper bound of the epithermal group was chosen to be below the energy of most threshold reactions, above the energy of most resolved resonances for radiative capture reactions, and to ensure that the fast group encompasses almost all of the Watt's fission spectrum.

Using the above definitions for neutron categories, an ideal converter would maximize the fast flux while minimizing the thermal and epithermal fluxes in order to minimize radiative capture reactions that might interfere with fast neutron damage and fast neutron cross-section calculations. We determined that an ideal solution should have thermal flux that is less than 0.2% of the total flux and an epithermal flux that is less than 10% of the total flux. As a result, the fast flux should be approximately 90% or more of the total flux at the sampling location.

Additionally, as discussed above, uranium enriched above 20% is classified as HEU. For this reason, although uranium with higher enrichment results in a much higher number of fissions per volume in a thermal reactor, we determined that the final design should, ideally, use uranium enriched to less than 20% to avoid the additional security and administrative requirements. Finally, to minimize costs, the percentage of U-235 used in the converter should be as low as possible. Having established these criteria, we started by evaluating the use of a converter in the TRIGA reactor's pneumatic transport tube system.

Chapter 3: The Pneumatic Tube Transport System

3.1 The TRIGA Reactor and the Pneumatic Tube Transport System

As previously discussed, the University of Texas at Austin is home to a 1.1 megawatt (MW) TRIGA Mark II nuclear research reactor [27]. TRIGA reactors were initially developed by General Atomics in the 1950s and are widely used for training, education, and research by governments, educational institutions, and industry [28]. Designed to be inherently safe and easy to operate, TRIGA reactors are open pool, light-water moderated reactors that use low-enriched uranium-zirconium hydride fuel elements and a graphite reflector [13, 28]. The reactor is controlled by three boron carbide control rods with an electric motor and rack and pinion drive, and one additional boron carbide control rod with a compressed air drive that is used to create a short 1500-MW pulse [26, 27].

The TRIGA reactor at UT provides a number of in-core radiation facilities for research, including a pneumatic tube transport system that enables the transfer of small samples into the reactor for short periods of irradiation. Figure 3.1 shows the layout of the pneumatic tube transport system.

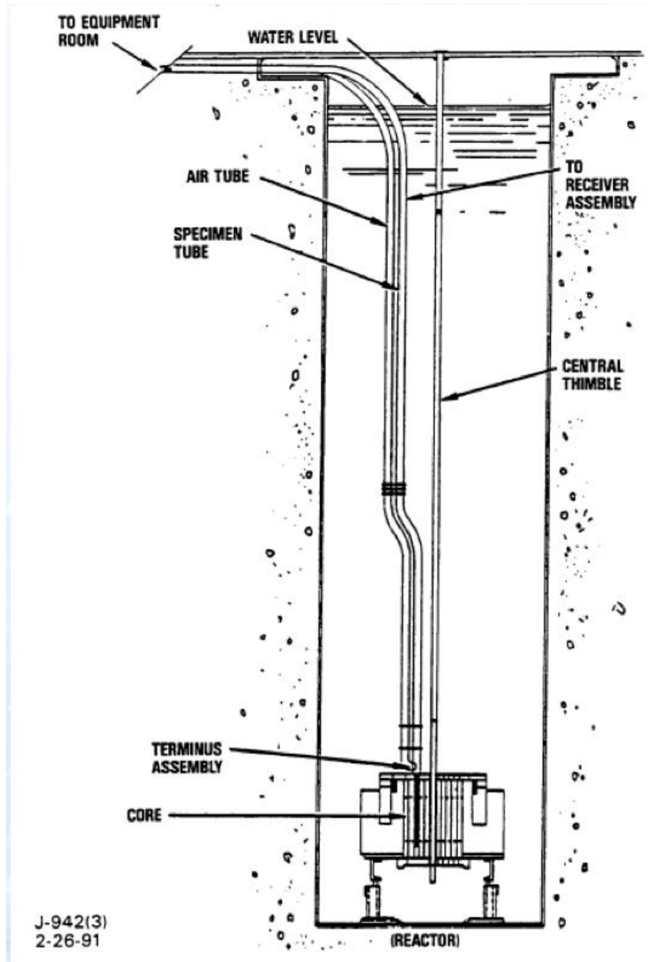

Figure 3.1: Pneumatic Tube Transport System [4].

The sample to be tested is loaded into a plastic, cylindrical vial approximately one-inch tall and a half-inch in diameter. The vial is then pneumatically transferred into the reactor core using a series of aluminum tubes that extend from the laboratory to the interior of the reactor core near the outer ring of the fuel elements. Because the sample terminus is located in the reactor core, the sample is subjected to the reactor's neutron flux, which, as discussed above, includes fast, epithermal, and thermal neutrons, and therefore will not accomplish the objectives of this project without modification.

Importantly, the pneumatic transport system can be operated with a cadmium liner. As can be seen in Figure 3.2, and as discussed previously, cadmium has an extraordinarily high microscopic cross section for absorption for thermal neutrons, especially below energies of approximately 0.7 eV.

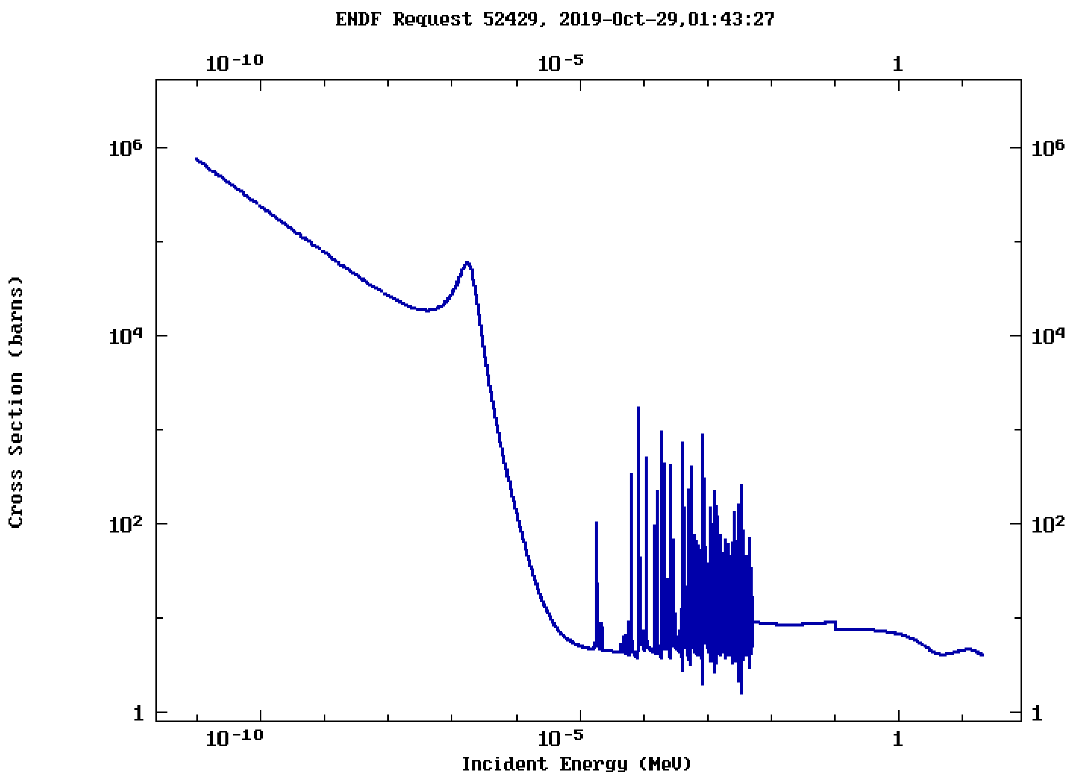

Figure 3.2: IAEA ENDF Total Microscopic Cross Section for Cd-113 [9].

This extremely high microscopic cross section for absorption means that a very thin layer of cadmium will absorb much of the thermal neutron flux in the reactor before it reaches the sample. Unfortunately, the cadmium liner has little effect on the epithermal flux, and as a result, the cadmium liner alone would not achieve the goals of this project.

3.2 Initial Simulations using the Pneumatic Transport Tube System

Initial analyses, however, centered on using the pneumatic transport tube system as a possible location to generate a fast spectrum for two reasons. First, the pneumatic transport tube system is already used to irradiate samples for various testing purposes. If the system could be adjusted to provide a fast neutron spectrum at the sample location, samples could easily be tested using an already existing and installed system. Second, and as stated above, the transport system includes an optional cadmium liner around the normal aluminum tubing. If the cadmium liner could be replaced with a uranium liner without affecting the rest of the system, the uranium might generate a fast spectrum by absorbing incoming thermal neutrons and fissioning, thereby releasing a large number of high energy prompt neutrons in the immediate vicinity of the sample.

The problem setup began with an MCNP input file provided by William Charlton for the UT TRIGA Mark II reactor that included the appropriate geometry and materials for the reactor [20, 33]. In the provided configuration, the boron carbide control rods were partially withdrawn to certain heights. An initial simulation of the provided MCNP input file indicated that the provided configuration resulted in a reactor that was approximately critical (i.e., at steady-state self-sustaining chain reaction operation), as desired, and therefore no control rod heights needed to be adjusted.

To determine if the uranium lining would generate a fast spectrum, the standard TRIGA file was modified by replacing the cadmium in the pneumatic transport tube system with highly enriched uranium. For the initial simulation, 95% enriched uranium was used to ensure the highest number of fissions per volume. If the desired fast spectrum was not accomplished with highly enriched uranium, a pneumatic transport tube using uranium enriched to a lower amount would not generate the desired spectrum as less enriched uranium would produce fewer fissions per volume, resulting in fewer fast neutrons in the immediate vicinity of the sample.

To measure the flux spectrum, the MCNP file was modified to add a simulated sample cylinder approximately 2.54 cm tall with a radius of 0.635 cm and filled with air inside the pneumatic transfer tube at the vertical centerline of the reactor. The MCNP file was also modified to add an F4 tally to the sample cylinder. F4 tallies provide a track length estimate of the flux by recording the total track length of all particles in a designated cell (in this case, the sample cylinder that was created) per source particle simulated and per unit volume. In other words, MCNP normalizes the results per fission neutron created, and these results must be scaled using a conversion factor based on the number of actual fission neutrons created in the reactor, which is a function of reactor power. Equation (3) shows the calculation of the conversion factor used to scale the MCNP F4 tally results to 950 kW, which is the typical operating power for the UT-NETL reactor.

$$(950{,}000\,W) * \left(\frac{1\,\frac{J}{s}}{1\,W}\right) * \left(\frac{MeV}{1.60219X10^{-13}\,J}\right) * \left(\frac{1\,Fission}{200\,MeV}\right) * \left(\frac{2.43\,Neutrons}{1\,Fission}\right) = 7.2042\,X\,10^{16}\,Neutrons/s \quad (3)$$

In addition to the conversion factor needed to scale the MCNP results to 950 kW, the F4 tally needed to be modified to distinguish flux by energy groups. A tally modifier card was added to the F4 tally to divide the results of the tally into the three energy bins listed in Table 2.1. As a result of the above two modifications, tally results would now provide a flux that corresponds to 950 kW reactor power and that flux would be divided into thermal, epithermal, fast, and total flux (i.e., all energies).

Having completed the above modifications, the simulation was run using MCNP6 with 50,000 particles per cycle for 100 cycles. Table 3.1 shows the results of that simulation as compared to a similarly located sample in the pneumatic transport tube system with no lining as well as a sample in the same system with the cadmium lining. Note that the errors expressed in Table 3.1 and subsequent tables are relative errors (i.e., the 1-σ standard deviation divided by the mean). Relative errors will be higher in energy bins where fewer particles were detected as the results are more uncertain. In general, errors greater than 0.10 are considered unreliable. In several cases throughout this report, the relative error in the thermal group may be higher than 0.10 due to the very low number of neutrons that survive in the thermal group; however, it is important to note that thermal flux estimates are not directly used in this report. Instead of requiring a precise thermal flux estimate for each simulation, this report only requires that the thermal flux be as low as reasonably achievable, and thus the additional effort required to obtain accurate estimates of the thermal energy group (i.e., very long computer run times) was considered to be unreasonable in light of the minimal benefits gained at this stage of the analysis.

Pneumatic Tube with No Lining			
Upper Energy Bound (MeV)	Flux at 950 kW (n/cm^2*s)	Error	Percentage of Total Flux
7.00E-07	9.825E+12	0.0299	52.9%
1.00E-02	3.231E+12	0.0486	17.4%
2.00E+01	5.508E+12	0.0377	29.7%
Total	1.856E+13	0.0216	
Pneumatic Tube with Cadmium Lining			
Upper Energy Bound (MeV)	Flux at 950 kW (n/cm^2*s)	Error	Percentage of Total Flux
7.00E-07	1.008E+11	0.2914	1.3%
1.00E-02	2.791E+12	0.0534	35.5%
2.00E+01	4.979E+12	0.0393	63.3%
Total	7.870E+12	0.0316	
Pneumatic Tube with Enriched Uranium Lining			
Upper Energy Bound (MeV)	Flux at 950 kW (n/cm^2*s)	Error	Percentage of Total Flux
7.00E-07	9.249E+11	0.0855	7.2%
1.00E-02	2.952E+12	0.0500	22.9%
2.00E+01	9.031E+12	0.0299	70.0%
Total	1.291E+13	0.0248	

Table 3.1: Pneumatic Tube with Highly Enriched Uranium.

Table 3.1 shows that, as expected, the addition of the highly enriched uranium resulted in a significantly higher absolute value of the fast flux as compared to the unlined tube. However, although the thermal and epithermal fluxes were reduced, both fluxes were above the threshold limits previously established (i.e., greater than 0.2% thermal flux and greater than 10% epithermal flux). In particular, thermal flux was much higher than the cadmium-lined configuration, increasing from approximately 1.3% of the total flux in the cadmium-lined configuration to approximately 7.2% of the total flux in the uranium-lined configuration. As a result, it was determined that replacing the cadmium liner with a uranium liner would not accomplish the desired flux spectrum.

Note also the low tally and the correspondingly high error in the thermal flux for the cadmium-lined version of the pneumatic transport tube system. Although this error was greater than 0.10 and is therefore considered unreliable, the error rates for the epithermal, fast, and total fluxes were well within reliability. Comparing the total epithermal and fast fluxes with the total flux provides confidence that the thermal flux is, in fact, minimal despite the high error.

Although insertion of the highly enriched uranium was not successful, these results were informative in confirming that the addition of a thin layer of uranium does increase the fast flux while also confirming that the addition of a thin layer of cadmium does absorb a significant amount of the thermal flux. Based on these results, we posited that a combination of uranium and cadmium might achieve the desired flux spectrum. Unfortunately, the size constraints of the pneumatic tube transport system do not provide sufficient room for such a two-stage system, and the focus of our research moved to the TRIGA reactor's 3-Element (3-L) Facility, discussed in the next section.

Chapter 4: The 3-Element Facility

4.1 The 3-L Facility, the 3-L Irradiator, and the Addition of Cadmium

The UT-NETL reactor contains three elements in the reactor that are not filled with either a control rod or fuel elements, called the 3-L Facility. Figure 4.1 shows the 3-L Facility with no irradiator installed. Figure 4.2 shows a schematic of the irradiator that can be installed in the 3-L Facility. Finally, Figure 4.3 is a picture of the irradiator inserted into the 3-L Facility.

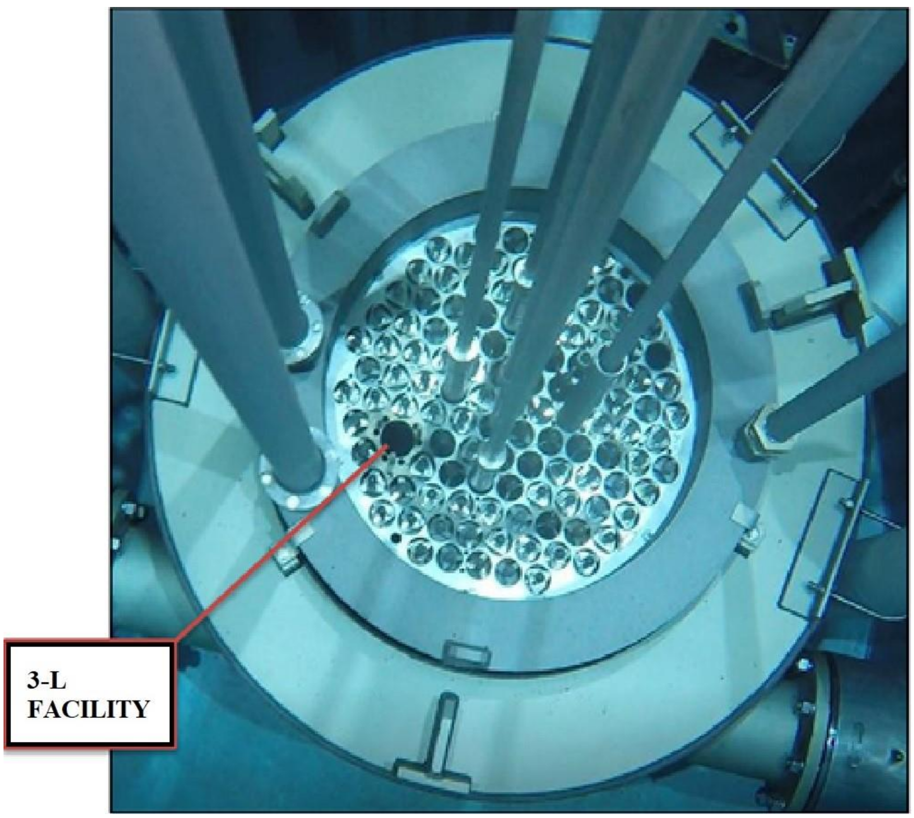

Figure 4.1: 3-Element Facility [28].

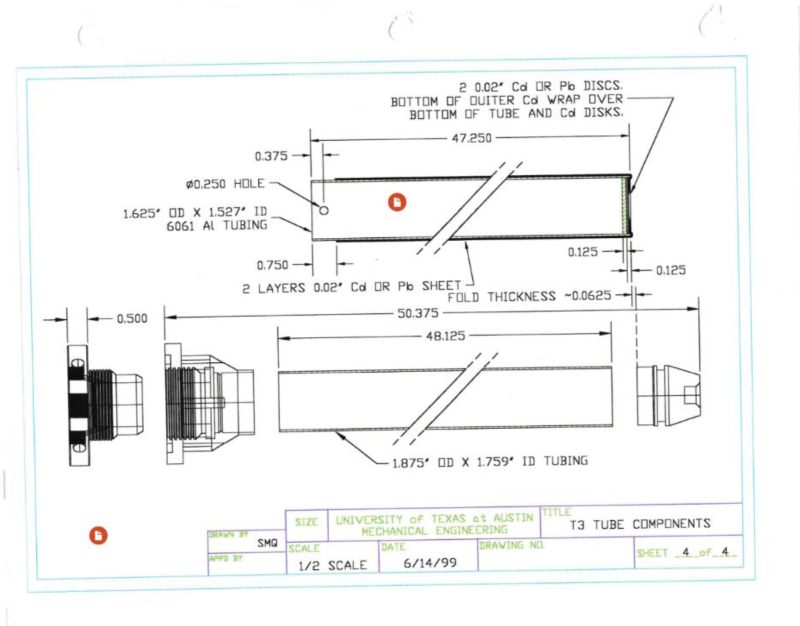

Figure 4.2: 3-Element Irradiator [18].

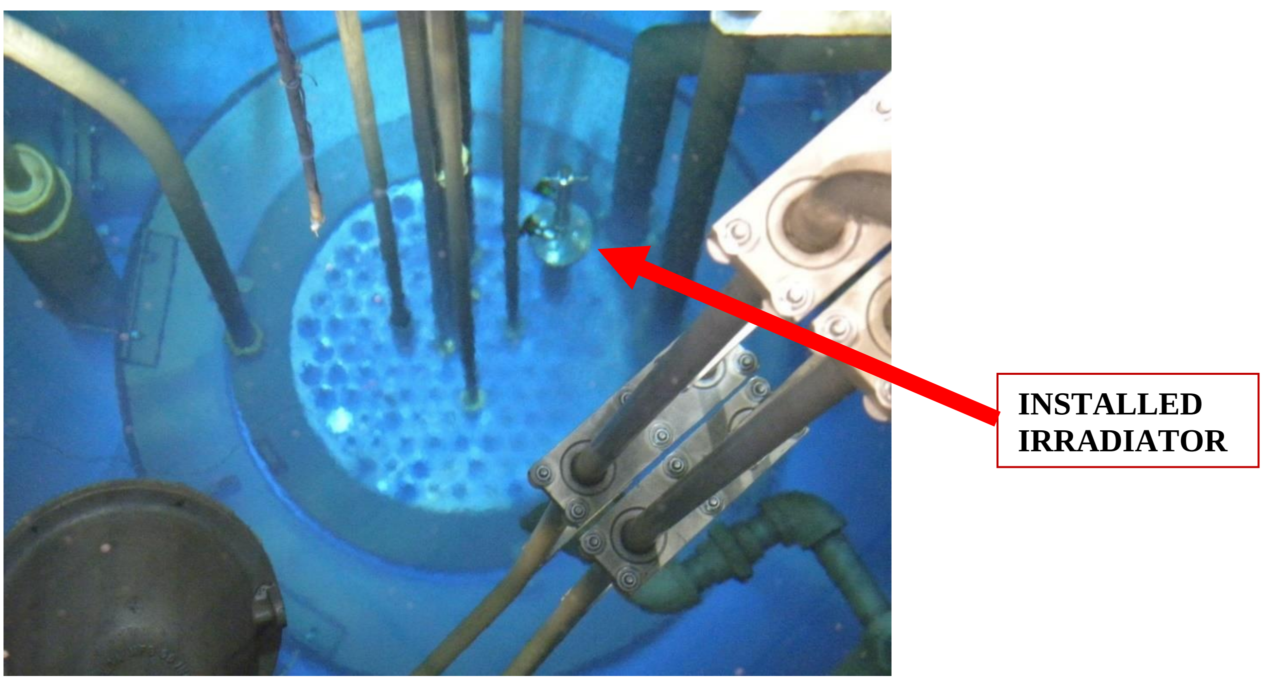

Figure 4.3: 3-Element Facility with Irradiator Installed [34].

The first step in modeling the 3-L Facility was to modify the MCNP file to create a series of concentric circles representing layers of cadmium and uranium inside the irradiator. The reactor core in the provided MCNP file is divided into a lattice of hexagonal universes, with most universes housing a single control rod or single fuel element. Because the 3-L Facility occupies the equivalent of three spaces in the reactor core, the 3-L Facility is split up among three different universes in the MCNP input file—namely, Universes 2, 12, and 13. As a result, concentric cylinders were added to each of these three universes, ensuring that the exact middle of each cylinder was centered on the location where Universes 2, 12, and 13 meet. In this way, although the portions of each cylinder that cross over each universe boundary are cut off, the cylinders in Universes 2, 12, and 13 all combine one-third of a cylinder to provide a complete cylinder in the 3-L Facility. Figure 4.4 shows a visual representation of 3-L Facility created in MCNP.

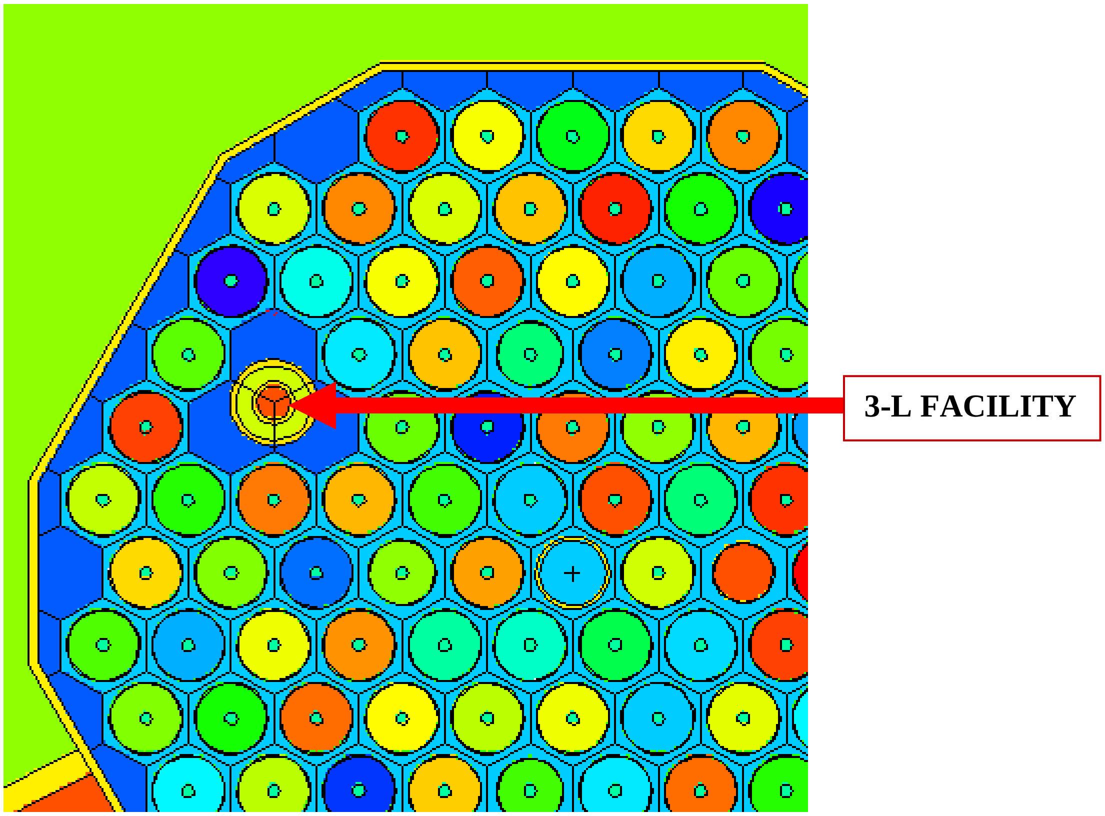

Figure 4.4: MCNP Output Showing Concentric Cylinders in Universes 2, 12, and 13.

For the initial simulations, each universe contained an aluminum tube in the middle of the irradiator with a small sample cylinder, again 2.54 cm tall with a radius of 0.635 cm, located at the vertical midline of the reactor core. Because each sample cylinder was cut off by the edges of the universe and therefore only occupied one-third of the sample volume (exactly like the concentric cylinders discussed above), the MCNP file was modified to have three F4 tallies for the sample cylinder—one tally for each universe. As before, an energy modifier was applied to each F4 tally to provide discrete energy distributions for thermal, epithermal, and fast neutrons, and each F4 tally was multiplied by the conversion factor calculated in Equation (3) to modify the results to equal neutron flux at 950 kW. The results for each tally were averaged.

To determine the ideal placement of the cadmium in relation to the uranium, three scenarios were evaluated: uranium with a 1/16-inch cadmium layer outside the uranium, uranium with a 1/16-inch cadmium layer inside the uranium, and uranium with a 1/32-inch cadmium layer inside the uranium and a 1/32-inch cadmium layer outside the uranium. The results of these three simulations are provided the results in Table 4.1.

Cadmium Outside Uranium			
Upper Energy Bound (MeV)	Flux at 950 KW (n/cm^2*s)	Error	Percentage of Total Flux
7.00E-07	1.895E+09	0.3333	< 0.01%
1.00E-02	5.172E+11	0.0949	7.4%
2.00E+01	6.427E+12	0.0319	92.5%
Total	6.946E+12	0.0303	
Cadmium Inside Uranium			
Upper Energy Bound (MeV)	Flux at 950 KW (n/cm^2*s)	Error	Percentage of Total Flux
7.00E-07	< 6.0E+09	N/A	< 0.01%
1.00E-02	9.276E+11	0.0712	6.6%
2.00E+01	1.319E+13	0.0225	93.4%
Total	1.412E+13	0.0215	
Cadmium Inside and Outside the Uranium			
Upper Energy Bound (MeV)	Flux at 950 KW (n/cm^2*s)	Error	Percentage of Total Flux
7.00E-07	< 6.0E+09	N/A	< 0.01%
1.00E-02	5.056E+11	0.0986	7.2%
2.00E+01	6.513E+12	0.0318	92.8%
Total	7.019E+12	0.0303	

Table 4.1: MCNP Results from Varying the Placement of Cadmium.

Overall, these results confirmed the possibility of using a combination of uranium and cadmium to produce a fast spectrum. In each case, over 90% of the total flux was in the fast group with almost no thermal flux detected, and in each case, epithermal flux was less than 10% of the total flux. It is important to note again, at this point and for subsequent results, that the thermal flux is extremely low, and the statistical precision of MCNP's calculation limits the ability to provide a good estimator for the flux (without significant calculational complexity and computational effort). For the "Cadmium Outside the

Uranium" case, the uncertainty in the result is 0.3333 with a mean value of 1.895 X 10^9 n/cm^2-s. Given the high error, this estimate is unreliable; however, we can reasonably state that the thermal flux is less than 6.0 X 10^9 n/cm^2-s (i.e., we are over 99% confident that the true mean is less than the estimated mean plus ten times the estimated 1-σ standard deviation). For the other cases and for subsequent cases, when a mean estimate of the flux was below 2.0 X 10^9 or if MCNP registered a flux of zero, we listed "< 6.0E+09" with an error listed as "N/A" to signify that we do not have a good estimate of the mean value of the flux but are reasonably confident that it is less than 6.0 X 10^9 n/cm^2-s. As discussed previously, the thermal flux value is not used directly in these analyses as the analyses were primarily concerned with demonstrating that the thermal flux is likely below the threshold of 0.2% that was previously established.

Regarding the placement of the cadmium, the results in Table 4.1 show that there was minimal difference in the three cadmium locations with slightly better results when the cadmium was placed inside of the uranium (i.e., the cadmium is located between the uranium and the sample). In this configuration, the fast flux as a percentage of total flux and the absolute value of the fast flux is higher than the other configurations. These higher flux values are likely caused by the fact that, if the cadmium is located outside of the uranium, fewer thermal neutrons reach the uranium to cause fission, meaning that fewer fast neutrons are produced in the vicinity of the sample. By locating the cadmium inside of the uranium, thermal neutrons produced in the reactor are able to reach the uranium and cause fission, while the cadmium remains in place to filter out any remaining thermal neutrons immediately prior to reaching the sample. As a result, the optimal location of the cadmium was determined to be between the uranium and the sample.

Finally, to increase the accuracy of the results, a layer of aluminum was added outside of the uranium to represent the shell of the irradiator, and the thickness of the uranium was decreased from 1.23 cm to 0.96393 cm to accommodate the addition of the aluminum. This new configuration was simulated in MCNP, and the results showed that the addition of the outer aluminum layer and the reduction of the uranium's thickness reduced fast flux to 91.4% of the total flux while increasing epithermal flux to 8.6% of total flux. These results were slightly worse than the prior results, most likely because there is now less uranium to interact with neutrons and fission, but the results were still within the goals of the design. Full results for the three uranium-cadmium filter simulations as well as the simulation involving the addition of an aluminum layer are available in Appendix 1.

4.2 Varying Uranium Enrichment

Although the above results proved the feasibility of using a combination of uranium and cadmium to produce a fast spectrum, those results were achieved using very highly enriched uranium—around 93% U-235. As discussed above, higher enrichment is more expensive, and enrichment levels above 20% U-235 classify the material as "highly enriched uranium," requiring significant security and administrative requirements. As a result, optimizing the design required lowering the enrichment as far as possible, and in no case higher than 20% U-235. In order to gain an understanding of how vital uranium enrichment was to the design, a series of simulations was run using the same input file as before (i.e., including the aluminum outer layer) with uranium enrichment levels decreasing from 90% U-235 to 10% U-235 in 10% increments, with an additional simulation at 5% U-235. The results of those simulations are presented in Table 4.2.

Enrichment (%)	Total Flux (n/cm^2*s)	Total Error	Fast Flux (n/cm^2*s)	Fast Error	Epithermal Flux (n/cm^2*s)	Epithermal Error
93	1.272E+13	0.0229	1.163E+13	0.0243	1.092E+12	0.0669
90	1.248E+13	0.0228	1.142E+13	0.0241	1.062E+12	0.0692
80	1.217E+13	0.0251	1.109E+13	0.0251	1.084E+12	0.0695
70	1.178E+13	0.0238	1.066E+13	0.0253	1.121E+12	0.0682
60	1.091E+13	0.0247	9.711E+12	0.0265	1.194E+12	0.0656
50	1.101E+13	0.0251	9.656E+12	0.0272	1.348E+12	0.0626
40	1.052E+13	0.0253	9.138E+12	0.0274	1.378E+12	0.0644
30	1.040E+13	0.0260	8.820E+12	0.0286	1.576E+12	0.0605
20	9.492E+12	0.0271	7.958E+12	0.0301	1.516E+12	0.0615
10	8.853E+12	0.0279	7.046E+12	0.0319	1.778E+12	0.0566
5	7.897E+12	0.0300	6.104E+12	0.0346	1.772E+12	0.0599

Enrichment (%)	Thermal Flux (n/cm^2*s)	Thermal Error	Fast Flux Percentage of Total Flux	Epithermal Flux Percentage of Total Flux	Thermal Flux Percentage of Total Flux
93	< 6.0E+09	N/A	91.4%	8.6%	< 0.01%
90	2.125E+09	0.6667	91.5%	8.5%	0.02%
80	< 6.0E+09	N/A	91.1%	8.9%	0.01%
70	2.520E+09	1.0000	90.5%	9.5%	0.02%
60	< 6.0E+09	N/A	89.0%	11.0%	< 0.01%
50	2.195E+09	0.6667	87.7%	12.2%	0.02%
40	4.074E+09	0.8304	86.9%	13.1%	0.04%
30	7.600E+09	0.7194	84.8%	15.1%	0.07%
20	1.816E+10	0.4966	83.8%	16.0%	0.19%
10	2.936E+10	0.4835	79.6%	20.1%	0.33%
5	2.194E+10	0.4674	77.3%	22.4%	0.28%

Table 4.2: MCNP Results from Varying Enrichment.

As expected, as enrichment decreased, the absolute value of the fast flux and the percentage of total flux attributable to the fast flux decreased. Additionally, thermal flux and epithermal flux percentages of total flux both increased, exceeding the respective limits of 0.2% and 10% as enrichment levels decreased. In particular, epithermal flux surpassed the 10% threshold as soon as enrichment decreased to 60% U-235—way above the 20% limit for IAEA safeguards. At 20% enrichment, the epithermal flux was 16% of the total flux—well above the 10% limit previously established. The results appeared reliable given the error rates for epithermal, fast, and total fluxes at all enrichment levels.

Given the fact that increasing the thickness of the cadmium would have almost no effect on the epithermal flux because of cadmium's smaller microscopic cross section in the epithermal energy region, but operating under the constraint that enrichment be less than 20%, it was determined that another material was needed to filter out the epithermal flux. In this case, it was boron.

4.3 The Addition of Boron

While cadmium has an extremely high cross section for low energy neutrons, boron has a high cross section across a range of epithermal neutron energies, as shown in Figure 4.5. We posited, therefore, that adding a layer of boron between the uranium and cadmium should result in the boron attenuating the epithermal flux while the cadmium attenuates the thermal flux, allowing the fast neutrons generated by the fission of the uranium to reach the sample. To test this hypothesis, the MCNP file was modified to add a 1/16-inch layer of boron (95% B-10) between the layer of uranium and cadmium, and a simulation was run with uranium at 20% enrichment. The results showed a fast flux to total flux percentage of 92.8% and an epithermal to total flux percentage of 7.2%—results that met the criteria for a successful design.

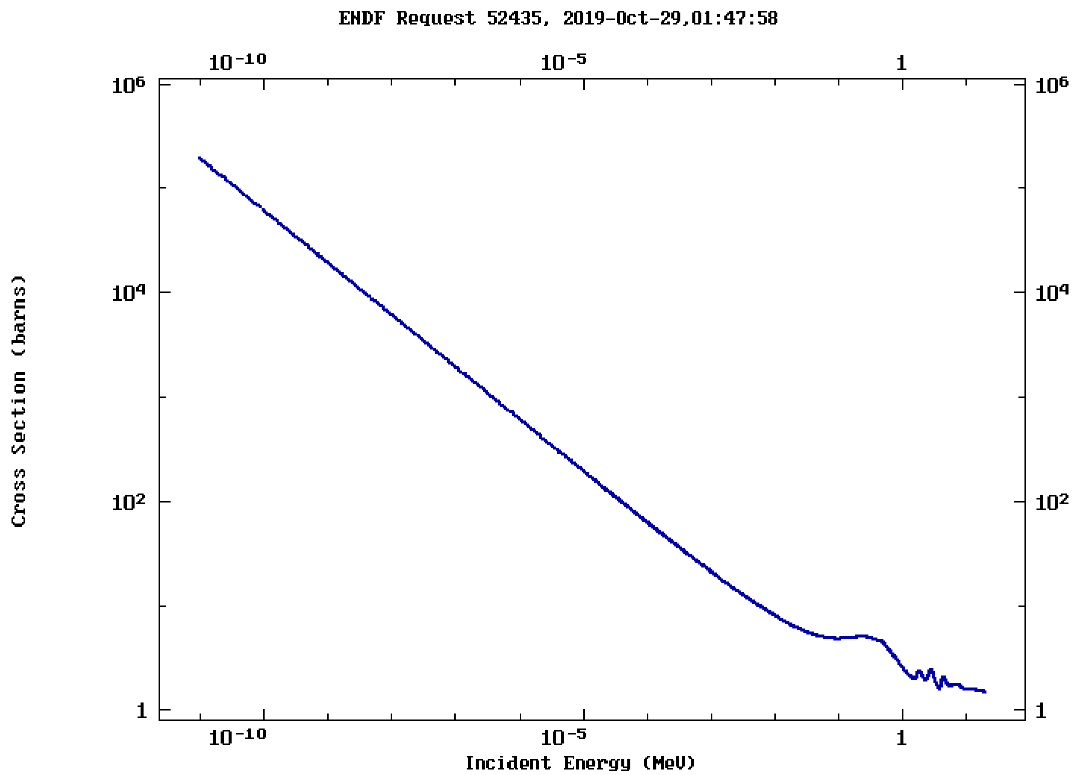

Figure 4.5: IAEA ENDF Total Microscopic Cross Section for B-10 [9].

The full results for all the enrichment simulations as well as the addition of boron are available in Appendix 2.

4.4 Optimization

The above results indicated that a three-layer system of uranium, boron, and cadmium should produce the desired fast spectrum. To separate the materials, a thin layer of aluminum approximately 0.064-inches thick was added to the MCNP file to divide each layer (in addition to the layers of aluminum on the outside and inside of the irradiator itself). Although this combination appeared to meet the project's goals, the system needed to be optimized to find the combination of uranium enrichment, uranium thickness, boron thickness, and cadmium thickness that would produce the best spectrum at minimal cost. The outer and inner aluminum tubes constrained the maximum thickness of the entire system, but within those constraints, the uranium, boron, and cadmium thicknesses could all be varied at the expense of each other. At the same time, although the results above clearly indicated that enrichment at 20% provided a viable solution, 20% enriched uranium is expensive and any reduction in uranium enrichment would help lower the overall cost of the system. Given the four variables that could be adjusted (uranium enrichment and the three material thicknesses), there were five parameters that the design should optimize: (1) maximizing the absolute value of the fast flux, (2) maximizing the fast flux to total flux percentage, (3) minimizing the epithermal flux to total flux percentage, (4) minimizing the thermal flux to total flux percentage, and (5) minimizing the uranium enrichment.

To effectively compare the effect of different combinations of variables on the desired parameters, a multi-attribute utility analysis was performed. First, two of the five parameters were eliminated by setting a maximum threshold of 0.02% thermal flux to total flux percentage (i.e., any combination with thermal flux higher than 0.02% would be rejected) and by recognizing that parameters (2) through (4) are only two parameters because these three parameters have to add up to 100%, (i.e., the third parameter is equal to 100% minus the other two parameters). Second, after eliminating these two parameters, the three remaining parameters—maximizing absolute value of fast flux, minimizing epithermal flux to total flux percentage, and minimizing uranium enrichment—were each assigned a utility function U_1, U_3, and U_5, respectively. Each utility value was assumed to be a linear function between a defined maximum acceptable x value (i.e., best acceptable value of the parameter) and a defined minimal acceptable x value (i.e., least acceptable value of the parameter). Each utility function, therefore, was then characterized by Equation (4).

$$U(x) = m * x + b \tag{4}$$

Given that the best acceptable value of *x* should produce a U of 1, and the least acceptable value of x should produce a U of 0, the slope (m) and intercept (b) of the linear function can be calculated such that any value of the parameter *x* produced by an MCNP simulation can be entered into the above formula to provide a utility value between 1 and 0.

Finally, to combine the utility values of the three individual parameters to create an overall utility value (*V*), each parameter's utility value was assigned a weight (*w*) that corresponds to that parameter's importance to the overall value of the solution. Multiplying each of the utility functions by its weighting factor gives an overall value for the solution, *V*, which ranges from 0 to 1, much like each utility function. Equation (5) was used to calculate the overall value for each solution.

$$V = w_1 U_1(x_1) + w_3 U_3(x_3) + w_5 U_5(x_5) \tag{5}$$

A higher *V* value indicates a better solution, with the goal to get as close to 1 as possible.

Table 4.3 shows the parameters available for optimization, the maximum and minimum values for each of the parameters that correspond to U values of 1 and 0, the calculated *m* and *b* values for each linear relationship, and the weighting factor *w* for each of the parameters being used for optimization.

Parameters	Goal	Utility	*X* Min (*U*=0)	*X* Max (*U*=1)	m	b	w
Absolute Value of the Fast Flux	Maximize	U_1	1.50E+12	1.50E+13	7.407E-14	-0.1111	0.40
Fast Flux Percentage of Total Flux	Maximize						
Epithermal Flux Percentage of Total Flux	Minimize	U_3	10%	0%	-10.00	1.0000	0.40
Thermal Flux Percentage of Total Flux	Minimize; < 0.2%						
Uranium Enrichment	Minimize; < 20%	U_5	20%	0.72%	-5.1867	1.0373	0.20

Table 4.3: Multi-Attribute Utility Analysis Parameters.

As an example, Table 4.3 shows that a maximum of 20% enrichment is acceptable, but 20% enrichment corresponds to a U_5 value of 0, which is less desirable than lower enrichment levels that would lead to higher U_5 values. Of note, Table 4.3 also shows that weighting factors were chosen such that maximizing the absolute value of the fast flux and minimizing the epithermal flux to total flux percentage were both considered to be twice as important as minimizing the uranium enrichment.

Using these utility factors, a series of simulations were run that varied boron thickness, cadmium thickness, and uranium enrichment. Because the entire system was limited by the size of the 3-L irradiator, the thickness of the uranium was increased or decreased depending on the relative increase or decrease in the combined thickness of the cadmium and boron layers. Finally, one additional adjustment was made prior to these simulations. Previous simulations used uranium metal for simplicity, but the following simulations replaced uranium metal with uranium oxide (U_3O_8) powder as uranium oxide powder would be used to build the proposed converter [11]. In total, eleven scenarios were run, and the results are shown in Table 4.4.

	x1	U1	x3	U3	x5	U5	V
Scenario 1 (3%, 1/16" B, 1/16" Cd)	2.934E+12	0.1063	16.598%	-0.6598	3%	0.8817	-0.0451
Scenario 2 (3%, 1/8" B, 1/16" Cd)	2.725E+12	0.0908	10.211%	-0.0211	3%	0.8817	0.2042
Scenario 3 (3%, 1/8" B, 1/32" Cd)	2.823E+12	0.0980	10.087%	-0.0087	3%	0.8817	0.2121
Scenario 4 (10%, 1/16" B, 1/16" Cd)	3.460E+12	0.1452	15.053%	-0.5053	10%	0.5187	-0.0403
Scenario 5 (10%, 1/8" B, 1/32" Cd)	3.195E+12	0.1255	10.799%	-0.0799	10%	0.5187	0.1220
Scenario 6 (15%, 1/8" B, 1/16" Cd)	3.084E+12	0.1173	10.380%	-0.0380	15%	0.2593	0.0836
Scenario 7 (20%, 1/8" B, 1/16" Cd)	3.445E+12	0.1440	9.967%	0.0033	20%	0.0000	0.0589
Scenario 8 (3%, 3/16" B, 1/16" Cd)	2.501E+12	0.0741	8.297%	0.1703	3%	0.8817	0.2741
Scenario 9 (10%, 3/16" B, 1/16" Cd)	2.560E+12	0.0785	8.943%	0.1057	10%	0.5187	0.1774
Scenario 10 (15%, 3/16" B, 1/16" Cd)	2.758E+12	0.0932	8.547%	0.1453	15%	0.2593	0.1472
Scenario 11 (20%, 3/16" B, 1/16" Cd)	3.060E+12	0.1158	8.788%	0.1212	20%	0.0000	0.0948

Table 4.4: Summary of Optimization Simulations.

Comparing the scenarios in Table 4.4, there appeared to be little advantage to increasing the thickness of the cadmium, probably because the thermal cross section for cadmium is so large and because the thermal flux is attenuated exponentially as it passes through the cadmium. As a result, and for ease of manufacturing, a cadmium thickness of 1/16 inch was selected as the optimal thickness.

Increasing the thickness of boron did, however, affect the epithermal flux. For example, a comparison of Scenarios 4 and 5 shows that an increase of boron thickness from 1/16 inch to 1/8 inch for the same uranium enrichment decreases the epithermal flux significantly. Based on these initial scenarios, an optimal configuration appeared to be a 3/16-inch layer of boron combined with a 1/16-inch layer of cadmium. Scenarios 8 through 11 utilize this combination of boron and cadmium but vary the uranium enrichment. As enrichment level increased, the ratio of epithermal flux remained relatively constant, probably because the boron thickness remained the same, but the absolute fast flux increased. Although maximizing the absolute value of the fast flux is a parameter of interest, the absolute value of the fast flux at 3% enrichment was within the parameter limits of the multi-attribute utility analysis, and increasing the value of the enrichment would incur significantly higher cost. As a result, Scenario 8 was chosen as the optimal solution. Full optimization results are available in Appendix 3.

Chapter 5: Final Results

With an ideal configuration determined, a more detailed flux spectrum could be determined. The three energy groups previously used in the F4 tally modifiers were replaced by the 63 energy groups in the CINDER90 library, which range in energies from 10^{-11} MeV to 25 MeV. Because of the greatly increased number of energy bins, fewer particles would be detected in each bin, resulting in higher error rates. To mitigate the increase in error rates in each bin, the KCODE card was modified to run 500,000 particles per cycle instead of 50,000, resulting in more neutrons detected in each energy bin per cycle and lowering the error rates. Additionally, a rand card was added to the MCNP deck to allow changing the random number seed. By changing the random number seed, three simulations of the same input file were run with different seed values to provide three independent measurements. The result of these three independent simulations were averaged to produce the final results, and the full results of all three simulations are available in Appendix 4. Additionally, the complete MCNP input file for one of these simulations is included in Appendix 5.

Figure 5.1 is a graph of the final results with neutron energy on a log scale and flux on a linear scale. For comparison, Figure 5.1 also shows the Watt's Fission Spectrum in orange.

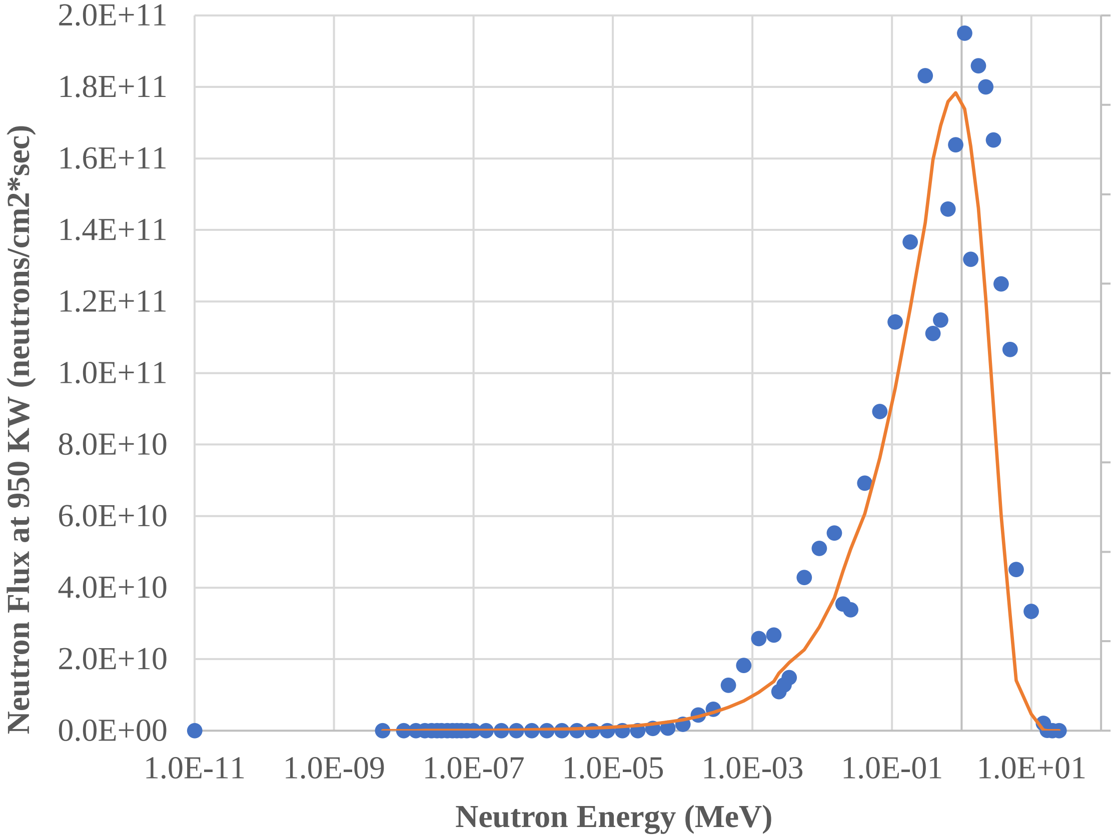

Figure 5.1: Total Flux v. Neutron Energy.

Note that uncertainties are plotted in Figure 5.1 but are not visible because of the small magnitude of most detected errors. Most flux values produced errors less than 0.01, although higher errors were calculated at very low flux levels corresponding to neutron energies between 3.727 X 10^{-5} MeV and 2.754 X 10^{-4} MeV. These large errors were generated because of the minimal neutron flux at these energies, resulting in fewer particle detections in these energy bins.

Figure 5.2 shows the same results on a log-log scale (note that flux values of 0 cannot be plotted on the log scale). The error values can be seen in Figure 5.2.

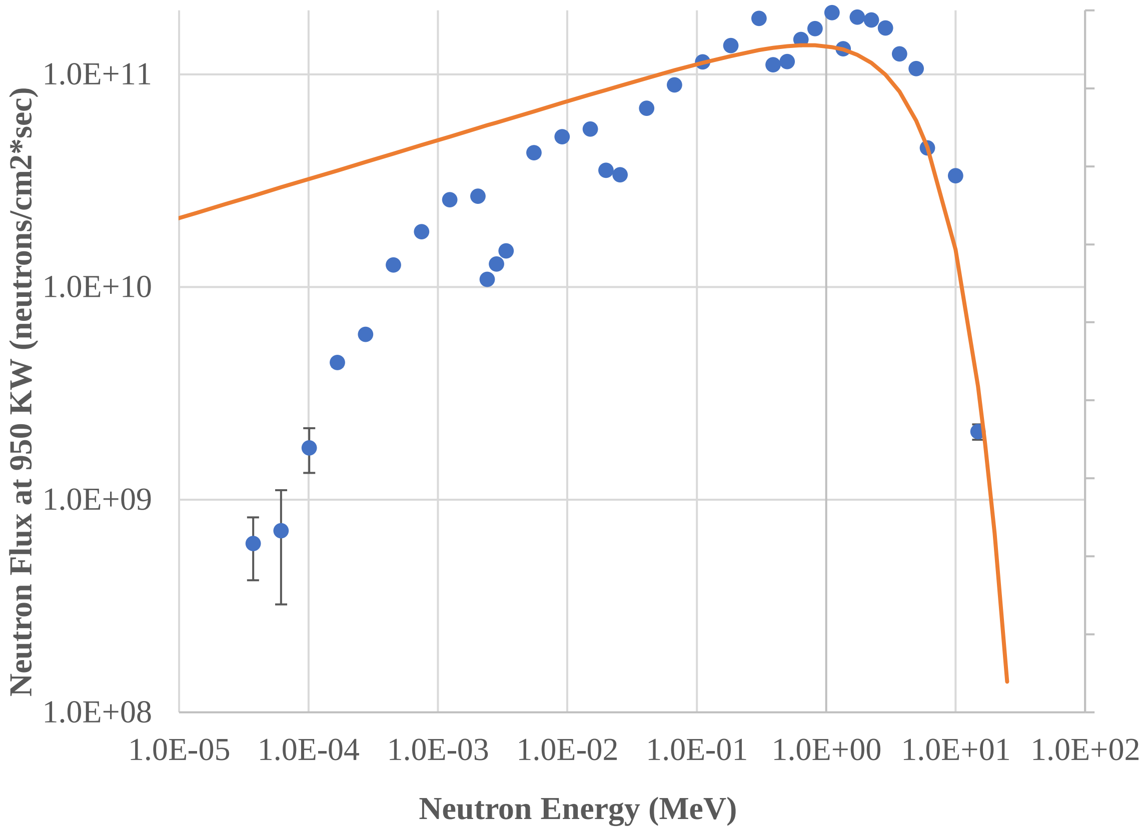

Figure 5.2: Total Flux v. Neutron Energy (Log-Log Scale).

Figures 5.1 and 5.2 clearly show that almost all of the flux received by the sample occurs at energies above 1.0 keV with the majority of the flux clustered around 1.0 MeV. In fact, the spectrum produced closely tracks the Watt's Fission Spectrum, indicating that the converter effectively removes most of the neutrons in the reactor core except those produced by fission near the sample location. Using the same energy ranges as before, the thermal flux is less than 0.2% of the total flux, and the epithermal flux is approximately 8.642% of the total flux, less than the 10% threshold previously established. Finally, the enrichment level was maintained well below the IAEA threshold of 20%, and at 3%, the enrichment level will minimize costs for uranium. It appears, therefore, that using a converter that consists of thin layers of uranium, boron, and cadmium will produce a fast neutron spectrum flux in a thermal reactor.

Chapter 6: Conclusion and Future Work

The above results show that a fast neutron flux spectrum can be generated in a thermal reactor using a converter consisting of thin layers of uranium, boron, and cadmium. Further research is recommended to determine if the system can be designed to ensure that the heat produced from the fission of uranium and the neutron captures in boron can be sufficiently dissipated to prevent melting the cadmium and the plastic sample vial. Additional calculations are also recommended to determine the reactivity worth of the irradiator to ensure that it is sufficiently low for licensing and operations and to determine whether converter performance degrades over time of use. Finally, assuming the other calculations are satisfactory, a prototype should be constructed and tested in the UT TRIGA reactor. If successful, this design may allow fast spectrum testing in a thermal reactor without significant modification to normal reactor operations, greatly increasing the versatility of TRIGA research reactors at the University of Texas and at dozens of other research reactors worldwide.

Appendices

Appendix 1: Results from Varying the Placement of Cadmium

Pneumatic Tube with No Lining							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000305	7.2042E+16	7.00E-07	1.36376E-04	6.81903E+02	9.82480E+12	52.9%	0.0299
		1.00E-02	4.48446E-05	2.24231E+02	3.23070E+12	17.4%	0.0486
		2.00E+01	7.64515E-05	3.82271E+02	5.50772E+12	29.7%	0.0377
		Total	2.57672E-04	1.28840E+03	1.85632E+13		0.0216

Pneumatic Tube with Cadmium Lining							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5001654	7.2042E+16	7.00E-07	1.39856E-06	6.99304E+00	1.00755E+11	1.3%	0.2914
		1.00E-02	3.87378E-05	1.93696E+02	2.79075E+12	35.5%	0.0534
		2.00E+01	6.91079E-05	3.45551E+02	4.97867E+12	63.3%	0.0393
		Total	1.09244E-04	5.46239E+02	7.87016E+12		0.0316

Pneumatic Tube with Enriched Uranium Lining							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000172	7.2042E+16	7.00E-07	1.28385E-05	6.41947E+01	9.24911E+11	7.2%	0.0855
		1.00E-02	4.09782E-05	2.04898E+02	2.95215E+12	22.9%	0.0500
		2.00E+01	1.25359E-04	6.26817E+02	9.03112E+12	70.0%	0.0299
		Total	1.79176E-04	8.95911E+02	1.29082E+13		0.0248

3-L with Cadmium Outside Uranium							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
4999511	7.2042E+16	7.00E-07	2.63109E-08	1.31542E-01	1.89549E+09	0.0%	0.3333
		1.00E-02	7.17887E-06	3.58908E+01	5.17180E+11	7.4%	0.0949
		2.00E+01	8.92147E-05	4.46030E+02	6.42721E+12	92.5%	0.0319
		Total	9.64199E-05	4.82053E+02	6.94629E+12		0.0303

3-L with Cadmium Inside Uranium							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5003752	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.28762E-05	6.44295E+01	9.27630E+11	6.6%	0.0712
		2.00E+01	1.83052E-04	9.15947E+02	1.31874E+13	93.4%	0.0225
		Total	1.95928E-04	9.80377E+02	1.41151E+13		0.0215

3-L with Cadmium Inside and Outside Uranium							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000551	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	7.01775E-06	3.50926E+01	5.05573E+11	7.2%	0.0986
		2.00E+01	9.04064E-05	4.52082E+02	6.51306E+12	92.8%	0.0318
		Total	9.74241E-05	4.87174E+02	7.01863E+12		0.0303

3-L with Cadmium Inside Uranium with Aluminum Outer Layer							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
4999053	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.51620E-05	7.57955E+01	1.09230E+12	8.6%	0.0669
		2.00E+01	1.61447E-04	8.07084E+02	1.16310E+13	91.4%	0.0243
		Total	1.76610E-04	8.82881E+02	1.27233E+13		0.0229

Cadmium Outside Uranium (Tally 4)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999511	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	6.65477E-06	3.32706E+01	4.79423E+11	7.0%	0.0948
		2.00E+01	8.90803E-05	4.45358E+02	6.41752E+12	93.0%	0.0317
		Total	9.57351E-05	4.78629E+02	6.89695E+12		0.0302

Cadmium Outside Uranium (Tally 14)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999511	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	7.40501E-06	3.70214E+01	5.33472E+11	7.6%	0.0961
		2.00E+01	8.94006E-05	4.46959E+02	6.44060E+12	92.4%	0.0315
		Total	9.68056E-05	4.83981E+02	6.97407E+12		0.0300

Cadmium Outside Uranium (Tally 24)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999511	7.2042E+16	7.00E-07	7.89327E-08	3.94625E-01	5.68647E+09	0.1%	1.0000
		1.00E-02	7.47683E-06	3.73805E+01	5.38646E+11	7.7%	0.0937
		2.00E+01	8.91633E-05	4.45773E+02	6.42350E+12	92.2%	0.0325
		Total	9.67191E-05	4.83548E+02	6.96784E+12		0.0308

Cadmium Outside Uranium (Average)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999511	7.2042E+16	7.00E-07	2.63109E-08	1.31542E-01	1.89549E+09	0.0%	0.3333
		1.00E-02	7.17887E-06	3.58908E+01	5.17180E+11	7.4%	0.0949
		2.00E+01	8.92147E-05	4.46030E+02	6.42721E+12	92.5%	0.0319
		Total	9.64199E-05	4.82053E+02	6.94629E+12		0.0303

Cadmium Inside Uranium (Tally 4)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5003752	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.33508E-05	6.68041E+01	9.61819E+11	6.8%	0.0706
		2.00E+01	1.84294E-04	9.22161E+02	1.32769E+13	93.2%	0.0224
		Total	1.97645E-04	9.88967E+02	1.42387E+13		0.0215

Cadmium Inside Uranium (Tally 14)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5003752	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.22464E-05	6.12779E+01	8.82255E+11	6.5%	0.0716
		2.00E+01	1.77491E-04	8.88121E+02	1.27868E+13	93.5%	0.0226
		Total	1.89738E-04	9.49402E+02	1.36691E+13		0.0217

Cadmium Inside Uranium (Tally 24)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5003752	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.30315E-05	6.52064E+01	9.38816E+11	6.5%	0.0713
		2.00E+01	1.87371E-04	9.37558E+02	1.34986E+13	93.5%	0.0224
		Total	2.00402E-04	1.00276E+03	1.44374E+13		0.0214

Cadmium Inside Uranium (Average)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5003752	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.28762E-05	6.44295E+01	9.27630E+11	6.6%	0.0712
		2.00E+01	1.83052E-04	9.15947E+02	1.31874E+13	93.4%	0.0225
		Total	1.95928E-04	9.80377E+02	1.41151E+13		0.0215

Cadmium Inside and Outside the Uranium (Tally 4)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5000551	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	7.03778E-06	3.51928E+01	5.07016E+11	7.3%	0.1007
		2.00E+01	8.98874E-05	4.49487E+02	6.47567E+12	92.7%	0.0317
		Total	9.69251E-05	4.84679E+02	6.98268E+12		0.0303

Cadmium Inside and Outside the Uranium (Tally 14)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5000551	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	6.29706E-06	3.14888E+01	4.53653E+11	6.4%	0.1028
		2.00E+01	9.26369E-05	4.63236E+02	6.67375E+12	93.6%	0.0317
		Total	9.89340E-05	4.94725E+02	7.12740E+12		0.0304

Cadmium Inside and Outside the Uranium (Tally 24)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5000551	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	7.71840E-06	3.85963E+01	5.56049E+11	8.0%	0.0923
		2.00E+01	8.86948E-05	4.43523E+02	6.38975E+12	92.0%	0.0319
		Total	9.64132E-05	4.82119E+02	6.94580E+12		0.0302

Cadmium Inside and Outside the Uranium (Average)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5000551	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	7.01775E-06	3.50926E+01	5.05573E+11	7.2%	0.0986
		2.00E+01	9.04064E-05	4.52082E+02	6.51306E+12	92.8%	0.0318
		Total	9.74241E-05	4.87174E+02	7.01863E+12		0.0303

Cadmium Inside Uranium with Aluminum Outer Layer (Tally 4)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999053	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.61643E-05	8.08304E+01	1.16451E+12	9.1%	0.0670
		2.00E+01	1.62377E-04	8.11974E+02	1.16980E+13	90.9%	0.0247
		Total	1.78542E-04	8.92808E+02	1.28625E+13		0.0233

Cadmium Inside Uranium with Aluminum Outer Layer (Tally 14)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999053	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.50192E-05	7.51043E+01	1.08201E+12	8.5%	0.0668
		2.00E+01	1.60845E-04	8.04314E+02	1.15876E+13	91.5%	0.0241
		Total	1.75864E-04	8.79417E+02	1.26696E+13		0.0228

Cadmium Inside Uranium with Aluminum Outer Layer (Tally 24)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999053	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.43024E-05	7.15199E+01	1.03037E+12	8.2%	0.0668
		2.00E+01	1.61120E-04	8.05689E+02	1.16074E+13	91.8%	0.024
		Total	1.75423E-04	8.77212E+02	1.26378E+13		0.0227

Cadmium Inside Uranium with Aluminum Outer Layer (Average)							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999053	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.51620E-05	7.58182E+01	1.09230E+12	8.6%	0.0669
		2.00E+01	1.61447E-04	8.07326E+02	1.16310E+13	91.4%	0.0243
		Total	1.76610E-04	8.83146E+02	1.27233E+13		0.0229

Appendix 2: Results from Varying Enrichment and the Addition of Boron

Summary of Varying Enrichment and Initial Addition of Boron											
Enrichment (%)	**Total Flux (n/cm^2*s)**	**Total Error**	**Fast Flux (n/cm^2*s)**	**Fast Error**	**Epithermal Flux (n/cm^2*s)**	**Epithermal Error**	**Thermal Flux (n/cm^2*s)**	**Thermal Error**	**Fast Flux Percentage of Total Flux**	**Epithermal Flux Percentage of Total Flux**	**Thermal Flux Percentage of Total Flux**
93	1.27233E+13	0.0229	1.16310E+13	0.0243	1.09230E+12	0.0669	0.00000E+00	0.0000	91.4%	8.6%	0.00%
90	1.24818E+13	0.0228	1.14177E+13	0.0241	1.06196E+12	0.0692	2.12474E+09	0.6667	91.5%	8.5%	0.02%
80	1.21720E+13	0.0251	1.10865E+13	0.0251	1.08442E+12	0.0695	9.65079E+08	0.6667	91.1%	8.9%	0.01%
70	1.17831E+13	0.0238	1.06598E+13	0.0253	1.12076E+12	0.0682	2.51968E+09	1.0000	90.5%	9.5%	0.02%
60	1.09058E+13	0.0247	9.71141E+12	0.0265	1.19436E+12	0.0656	0.00000E+00	0.0000	89.0%	11.0%	0.00%
50	1.10059E+13	0.0251	9.65584E+12	0.0272	1.34785E+12	0.0626	2.19541E+09	0.6667	87.7%	12.2%	0.02%
40	1.05200E+13	0.0253	9.13805E+12	0.0274	1.37786E+12	0.0644	4.07376E+09	0.8304	86.9%	13.1%	0.04%
30	1.04039E+13	0.0260	8.82049E+12	0.0286	1.57575E+12	0.0605	7.60028E+09	0.7194	84.8%	15.1%	0.07%
20	9.49166E+12	0.0271	7.95786E+12	0.0301	1.51565E+12	0.0615	1.81609E+10	0.4966	83.8%	16.0%	0.19%
10	8.85279E+12	0.0279	7.04557E+12	0.0319	1.77785E+12	0.0566	2.93631E+10	0.4835	79.6%	20.1%	0.33%
5	7.89739E+12	0.0300	6.10361E+12	0.0346	1.77184E+12	0.0599	2.19406E+10	0.4674	77.3%	22.4%	0.28%
20 with B-10 layer	6.84535E+12	0.0318	6.35545E+12	0.0333	4.89901E+11	0.1066	0.00000E+00	0.0000	92.8%	7.2%	0.00%

93% Enriched							
Tally 4							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999053	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.61643E-05	8.08062E+01	1.16451E+12	9.1%	0.0670
		2.00E+01	1.62377E-04	8.11731E+02	1.16980E+13	90.9%	0.0247
		Total	1.78542E-04	8.92541E+02	1.28625E+13		0.0233
Tally 14							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999053	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.50192E-05	7.50818E+01	1.08201E+12	8.5%	0.0668
		2.00E+01	1.60845E-04	8.04073E+02	1.15876E+13	91.5%	0.0241
		Total	1.75864E-04	8.79153E+02	1.26696E+13		0.0228
Tally 24							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999053	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.43024E-05	7.14985E+01	1.03037E+12	8.2%	0.0668
		2.00E+01	1.61120E-04	8.05447E+02	1.16074E+13	91.8%	0.0240
		Total	1.75423E-04	8.76949E+02	1.26378E+13		0.0227
Average							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999053	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.51620E-05	7.57955E+01	1.09230E+12	8.6%	0.0669
		2.00E+01	1.61447E-04	8.07084E+02	1.16310E+13	91.4%	0.0243
		Total	1.76610E-04	8.82881E+02	1.27233E+13		0.0229

90% Enriched							
Tally 4							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5004225	7.2042E+16	7.00E-07	3.85907E-08	1.93117E-01	2.78015E+09	0.0%	1.0000
		1.00E-02	1.52262E-05	7.61953E+01	1.09693E+12	9.0%	0.0679
		2.00E+01	1.53915E-04	7.70225E+02	1.10883E+13	91.0%	0.0241
		Total	1.69180E-04	8.46615E+02	1.21881E+13		0.0228
Tally 14							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5004225	7.2042E+16	7.00E-07	4.98887E-08	2.49654E-01	3.59408E+09	0.0%	1.0000
		1.00E-02	1.38776E-05	6.94466E+01	9.99770E+11	8.0%	0.0703
		2.00E+01	1.59801E-04	7.99680E+02	1.15124E+13	92.0%	0.0242
		Total	1.73729E-04	8.69379E+02	1.25158E+13		0.0230
Tally 24							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5004225	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.51189E-05	7.56584E+01	1.08920E+12	8.5%	0.0693
		2.00E+01	1.61744E-04	8.09403E+02	1.16524E+13	91.5%	0.0239
		Total	1.76863E-04	8.85062E+02	1.27416E+13		0.0227
Average							
NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5004225	7.2042E+16	7.00E-07	2.94931E-08	1.47590E-01	2.12474E+09	0.0%	0.6667
		1.00E-02	1.47409E-05	7.37668E+01	1.06196E+12	8.5%	0.0692
		2.00E+01	1.58487E-04	7.93103E+02	1.14177E+13	91.5%	0.0241
		Total	1.73257E-04	8.67019E+02	1.24818E+13		0.0228

80% Enriched

Tally 4

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5006261	7.2042E+16	7.00E-07	8.04776E-09	4.02892E-02	5.79777E+08	0.0%	1.0000
		1.00E-02	1.51071E-05	7.56301E+01	1.08835E+12	8.9%	0.0691
		2.00E+01	1.55272E-04	7.77332E+02	1.11861E+13	91.1%	0.0252
		Total	1.70388E-04	8.53007E+02	1.22751E+13		0.0238

Tally 14

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5006261	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.47478E-05	7.38313E+01	1.06246E+12	8.7%	0.0691
		2.00E+01	1.54084E-04	7.71385E+02	1.11005E+13	91.3%	0.0251
		Total	1.68832E-04	8.45217E+02	1.21630E+13		0.0237

Tally 24

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5006261	7.2042E+16	7.00E-07	3.21404E-08	1.60903E-01	2.31546E+09	0.0%	1.0000
		1.00E-02	1.53029E-05	7.66103E+01	1.10245E+12	9.1%	0.0704
		2.00E+01	1.52314E-04	7.62524E+02	1.09730E+13	90.9%	0.0249
		Total	1.67649E-04	8.39295E+02	1.20778E+13		0.0236

Average

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5006261	7.2042E+16	7.00E-07	1.33961E-08	6.70641E-02	9.65079E+08	0.0%	0.6667
		1.00E-02	1.50526E-05	7.53572E+01	1.08442E+12	8.9%	0.0695
		2.00E+01	1.53890E-04	7.70414E+02	1.10865E+13	91.1%	0.0251
		Total	1.68956E-04	8.45840E+02	1.21720E+13		0.0237

70% Enriched

Tally 4

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4997809	7.2042E+16	7.00E-07	5.04886E-08	2.52332E-01	3.63730E+09	0.0%	1.0000
		1.00E-02	1.50365E-05	7.51496E+01	1.08326E+12	9.2%	0.0702
		2.00E+01	1.48712E-04	7.43234E+02	1.07135E+13	90.8%	0.0252
		Total	1.63799E-04	8.18636E+02	1.18004E+13		0.0238

Tally 14

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4997809	7.2042E+16	7.00E-07	8.00114E-09	3.99882E-02	5.76418E+08	0.0%	1.0000
		1.00E-02	1.68555E-05	8.42406E+01	1.21430E+12	10.3%	0.0655
		2.00E+01	1.46478E-04	7.32069E+02	1.05526E+13	89.7%	0.0254
		Total	1.63342E-04	8.16352E+02	1.17675E+13		0.0238

Tally 24

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4997809	7.2042E+16	7.00E-07	4.64355E-08	2.32468E-01	3.34531E+09	0.0%	1.0000
		1.00E-02	1.47793E-05	7.39890E+01	1.06473E+12	9.0%	0.0688
		2.00E+01	1.48710E-04	7.44481E+02	1.07134E+13	90.9%	0.0254
		Total	1.63536E-04	8.18704E+02	1.17815E+13		0.0239

Average

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4997809	7.2042E+16	7.00E-07	3.49751E-08	1.74930E-01	2.51968E+09	0.0%	1.0000
		1.00E-02	1.55571E-05	7.77931E+01	1.12076E+12	9.5%	0.0682
		2.00E+01	1.47967E-04	7.39928E+02	1.06598E+13	90.5%	0.0253
		Total	1.63559E-04	8.17897E+02	1.17831E+13		0.0238

60% Enriched							
Tally 4							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5001343	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.64668E-05	8.23561E+01	1.18630E+12	11.2%	0.0655
		2.00E+01	1.30352E-04	6.51935E+02	9.39082E+12	88.8%	0.0265
		Total	1.46819E-04	7.34292E+02	1.05771E+13		0.0247
Tally 14							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5001343	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.67841E-05	8.39430E+01	1.20916E+12	10.9%	0.0656
		2.00E+01	1.36654E-04	6.83454E+02	9.84483E+12	89.1%	0.0266
		Total	1.53438E-04	7.67396E+02	1.10540E+13		0.0248
Tally 24							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5001343	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.64851E-05	8.24476E+01	1.18762E+12	10.7%	0.0656
		2.00E+01	1.37400E-04	6.87185E+02	9.89857E+12	89.3%	0.0265
		Total	1.53885E-04	7.69632E+02	1.10862E+13		0.0247
Average							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5001343	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.65787E-05	8.29156E+01	1.19436E+12	11.0%	0.0656
		2.00E+01	1.34802E-04	6.74191E+02	9.71141E+12	89.0%	0.0265
		Total	1.51381E-04	7.57107E+02	1.09058E+13		0.0247
50% Enriched							
Tally 4							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5006859	7.2042E+16	7.00E-07	3.83645E-08	1.92086E-01	2.76386E+09	0.0%	1.0000
		1.00E-02	1.89330E-05	9.47949E+01	1.36397E+12	12.7%	0.0612
		2.00E+01	1.30679E-04	6.54291E+02	9.41438E+12	87.3%	0.0274
		Total	1.49651E-04	7.49281E+02	1.07812E+13		0.0251
Tally 14							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5006859	7.2042E+16	7.00E-07	5.30576E-08	2.65652E-01	3.82238E+09	0.0%	1.0000
		1.00E-02	2.00846E-05	1.00561E+02	1.44694E+12	13.0%	0.0610
		2.00E+01	1.34713E-04	6.74489E+02	9.70500E+12	87.0%	0.0273
		Total	1.54851E-04	7.75317E+02	1.11558E+13		0.0250
Tally 24							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5006859	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	1.71100E-05	8.56674E+01	1.23264E+12	11.1%	0.0656
		2.00E+01	1.36700E-04	6.84438E+02	9.84814E+12	88.9%	0.0270
		Total	1.53810E-04	7.70105E+02	1.10808E+13		0.0251
Average							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5006859	7.2042E+16	7.00E-07	3.04740E-08	1.52579E-01	2.19541E+09	0.0%	0.6667
		1.00E-02	1.87092E-05	9.36743E+01	1.34785E+12	12.2%	0.0626
		2.00E+01	1.34031E-04	6.71073E+02	9.65584E+12	87.7%	0.0272
		Total	1.52771E-04	7.64901E+02	1.10059E+13		0.0251

40% Enriched							
Tally 4							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000008	7.2042E+16	7.00E-07	1.46062E-07	7.30311E-01	1.05226E+10	0.1%	0.7617
		1.00E-02	1.89067E-05	9.45337E+01	1.36208E+12	13.3%	0.0660
		2.00E+01	1.23181E-04	6.15906E+02	8.87421E+12	86.6%	0.0276
		Total	1.42234E-04	7.11171E+02	1.02468E+13		0.0255
Tally 14							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000008	7.2042E+16	7.00E-07	4.55617E-09	2.27809E-02	3.28236E+08	0.0%	0.7296
		1.00E-02	1.80054E-05	9.00271E+01	1.29715E+12	12.6%	0.0638
		2.00E+01	1.25325E-04	6.26626E+02	9.02867E+12	87.4%	0.0278
		Total	1.43335E-04	7.16676E+02	1.03261E+13		0.0256
Tally 24							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000008	7.2042E+16	7.00E-07	1.90230E-08	9.51152E-02	1.37046E+09	0.0%	1.0000
		1.00E-02	2.04652E-05	1.02326E+02	1.47435E+12	13.4%	0.0634
		2.00E+01	1.32024E-04	6.60121E+02	9.51128E+12	86.6%	0.0269
		Total	1.52508E-04	7.62541E+02	1.09870E+13		0.0249
Average							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000008	7.2042E+16	7.00E-07	5.65471E-08	2.82736E-01	4.07376E+09	0.0%	0.8304
		1.00E-02	1.91258E-05	9.56290E+01	1.37786E+12	13.1%	0.0644
		2.00E+01	1.26843E-04	6.34218E+02	9.13805E+12	86.9%	0.0274
		Total	1.46026E-04	7.30130E+02	1.05200E+13		0.0253

30% Enriched							
Tally 4							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5004041	7.2042E+16	7.00E-07	8.11114E-08	4.05885E-01	5.84343E+09	0.1%	0.8250
		1.00E-02	2.06001E-05	1.03084E+02	1.48407E+12	14.5%	0.0614
		2.00E+01	1.21623E-04	6.08606E+02	8.76197E+12	85.5%	0.0285
		Total	1.42305E-04	7.12100E+02	1.02519E+13		0.0260
Tally 14							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5004041	7.2042E+16	7.00E-07	1.43687E-07	7.19016E-01	1.03515E+10	0.1%	0.6172
		1.00E-02	2.13006E-05	1.06589E+02	1.53454E+12	14.6%	0.0599
		2.00E+01	1.24028E-04	6.20641E+02	8.93523E+12	85.3%	0.0289
		Total	1.45473E-04	7.27953E+02	1.04802E+13		0.0262
Tally 24							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5004041	7.2042E+16	7.00E-07	9.16952E-08	4.58847E-01	6.60591E+09	0.1%	0.7159
		1.00E-02	2.37173E-05	1.18682E+02	1.70864E+12	16.3%	0.0601
		2.00E+01	1.21655E-04	6.08767E+02	8.76427E+12	83.6%	0.0284
		Total	1.45464E-04	7.27908E+02	1.04795E+13		0.0257
Average							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5004041	7.2042E+16	7.00E-07	1.05498E-07	5.27916E-01	7.60028E+09	0.1%	0.7194
		1.00E-02	2.18727E-05	1.09452E+02	1.57575E+12	15.1%	0.0605
		2.00E+01	1.22435E-04	6.12671E+02	8.82049E+12	84.8%	0.0286
		Total	1.44414E-04	7.22654E+02	1.04039E+13		0.0260

20% Enriched							
Tally 4							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000128	7.2042E+16	7.00E-07	2.52024E-07	1.26015E+00	1.81563E+10	0.2%	0.4978
		1.00E-02	2.12279E-05	1.06142E+02	1.52930E+12	15.8%	0.0624
		2.00E+01	1.12731E-04	5.63669E+02	8.12137E+12	84.0%	0.0304
		Total	1.34211E-04	6.71072E+02	9.66883E+12		0.0274
Tally 14							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000128	7.2042E+16	7.00E-07	1.96992E-07	9.84985E-01	1.41917E+10	0.1%	0.5421
		1.00E-02	2.07938E-05	1.03972E+02	1.49803E+12	15.8%	0.0609
		2.00E+01	1.10519E-04	5.52609E+02	7.96201E+12	84.0%	0.0302
		Total	1.31510E-04	6.57567E+02	9.47425E+12		0.0272
Tally 24							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000128	7.2042E+16	7.00E-07	3.07247E-07	1.53627E+00	2.21347E+10	0.2%	0.4499
		1.00E-02	2.10934E-05	1.05470E+02	1.51961E+12	16.3%	0.0611
		2.00E+01	1.08134E-04	5.40684E+02	7.79019E+12	83.5%	0.0297
		Total	1.29534E-04	6.47687E+02	9.33189E+12		0.0268
Average							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5000128	7.2042E+16	7.00E-07	2.52088E-07	1.26047E+00	1.81609E+10	0.2%	0.4966
		1.00E-02	2.10384E-05	1.05195E+02	1.51565E+12	16.0%	0.0615
		2.00E+01	1.10461E-04	5.52321E+02	7.95786E+12	83.8%	0.0301
		Total	1.31752E-04	6.58775E+02	9.49166E+12		0.0271

10% Enriched							
Tally 4							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5001747	7.2042E+16	7.00E-07	3.40109E-07	1.70114E+00	2.45021E+10	0.3%	0.5103
		1.00E-02	2.43937E-05	1.22011E+02	1.75737E+12	20.6%	0.0564
		2.00E+01	9.39621E-05	4.69975E+02	6.76922E+12	79.2%	0.0325
		Total	1.18696E-04	5.93687E+02	8.55110E+12		0.0283
Tally 14							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5001747	7.2042E+16	7.00E-07	2.86980E-07	1.43540E+00	2.06746E+10	0.2%	0.5007
		1.00E-02	2.52629E-05	1.26359E+02	1.81999E+12	21.0%	0.0562
		2.00E+01	9.46292E-05	4.73311E+02	6.81728E+12	78.7%	0.0318
		Total	1.20179E-04	6.01105E+02	8.65794E+12		0.0278
Tally 24							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5001747	7.2042E+16	7.00E-07	5.95658E-07	2.97933E+00	4.29124E+10	0.5%	0.4394
		1.00E-02	2.43771E-05	1.21928E+02	1.75618E+12	18.8%	0.0571
		2.00E+01	1.04803E-04	5.24198E+02	7.55022E+12	80.8%	0.0315
		Total	1.29776E-04	6.49107E+02	9.34932E+12		0.0277
Average							
NPS from MCNP	**Conversion to 950 kW**	**Energy Bin (MeV)**	**MCNP Tally (1/cm^2*s)**	**Total MCNP Flux (n/cm^2*s)**	**Flux at 950 kW (n/cm^2*s)**	**Percentage of Total Flux**	**Error**
5001747	7.2042E+16	7.00E-07	4.07582E-07	2.03862E+00	2.93631E+10	0.3%	0.4835
		1.00E-02	2.46779E-05	1.23433E+02	1.77785E+12	20.1%	0.0566
		2.00E+01	9.77981E-05	4.89161E+02	7.04557E+12	79.6%	0.0319
		Total	1.22884E-04	6.14633E+02	8.85279E+12		0.0279

5% Enriched

Tally 4

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5000073	7.2042E+16	7.00E-07	2.76164E-07	1.38084E+00	1.98954E+10	0.3%	0.5064
		1.00E-02	2.51333E-05	1.25668E+02	1.81065E+12	22.9%	0.0605
		2.00E+01	8.45278E-05	4.22645E+02	6.08955E+12	76.9%	0.0341
		Total	1.09937E-04	5.49693E+02	7.92008E+12		0.0297

Tally 14

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5000073	7.2042E+16	7.00E-07	2.45386E-07	1.22695E+00	1.76781E+10	0.2%	0.5017
		1.00E-02	2.37536E-05	1.18770E+02	1.71126E+12	21.7%	0.0603
		2.00E+01	8.57109E-05	4.28561E+02	6.17479E+12	78.1%	0.0352
		Total	1.09710E-04	5.48558E+02	7.90373E+12		0.0305

Tally 24

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5000073	7.2042E+16	7.00E-07	3.92109E-07	1.96057E+00	2.82483E+10	0.4%	0.3942
		1.00E-02	2.48967E-05	1.24485E+02	1.79361E+12	22.8%	0.0589
		2.00E+01	8.39300E-05	4.19656E+02	6.04649E+12	76.8%	0.0345
		Total	1.09219E-04	5.46103E+02	7.86836E+12		0.0299

Average

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
5000073	7.2042E+16	7.00E-07	3.04553E-07	1.52279E+00	2.19406E+10	0.3%	0.4674
		1.00E-02	2.45945E-05	1.22974E+02	1.77184E+12	22.4%	0.0599
		2.00E+01	8.47229E-05	4.23621E+02	6.10361E+12	77.3%	0.0346
		Total	1.09622E-04	5.48118E+02	7.89739E+12		0.0300

20% Enriched with 95% B-10 Layer

Tally 4

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999832	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	6.36798E-06	3.18388E+01	4.58762E+11	6.7%	0.1130
		2.00E+01	8.85273E-05	4.42622E+02	6.37769E+12	93.3%	0.0334
		Total	9.48953E-05	4.74461E+02	6.83645E+12		0.0320

Tally 14

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999832	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	7.07183E-06	3.53580E+01	5.09469E+11	7.5%	0.1010
		2.00E+01	8.76632E-05	4.38301E+02	6.31543E+12	92.5%	0.0335
		Total	9.47351E-05	4.73660E+02	6.82491E+12		0.0319

Tally 24

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999832	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	6.96082E-06	3.48029E+01	5.01472E+11	7.3%	0.1059
		2.00E+01	8.84654E-05	4.42312E+02	6.37323E+12	92.7%	0.0330
		Total	9.54262E-05	4.77115E+02	6.87470E+12		0.0316

Average

NPS from MCNP	Conversion to 950 kW	Energy Bin (MeV)	MCNP Tally (1/cm^2*s)	Total MCNP Flux (n/cm^2*s)	Flux at 950 kW (n/cm^2*s)	Percentage of Total Flux	Error
4999832	7.2042E+16	7.00E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.0%	0.0000
		1.00E-02	6.80021E-06	3.39999E+01	4.89901E+11	7.2%	0.1066
		2.00E+01	8.82186E-05	4.41078E+02	6.35545E+12	92.8%	0.0333
		Total	9.50189E-05	4.75078E+02	6.84535E+12		0.0318

Appendix 3: Results from Optimization using Multi-Attribute Utility Analysis

Multi-Attribute Utility Analysis Parameters and Equations									
Parameter	**Goal**	**Utility**	**X Min**	**X Max**	**U Min**	**U Max**	**m**	**b**	**w**
Absolute Value of the Fast Flux	**Maximize**	U1	1.50E+12	1.50E+13	0	1	7.40741E-14	-0.1111111	0.4
Fast Flux Percentage of Total Flux	**Maximize**								
Epithermal Flux Percentage of Total Flux	**Minimize**	U3	10%	0%	0	1	-10.00000	1.0000000	0.4
Thermal Flux Percentage of Total Flux	**Minimize; less than 0.2%**								
Uranium Enrichment	**Minimize; less than 20%**	U5	20%	0.72%	0	1	-5.18672	1.037344398	0.2
Equations									
V=w1*U1(x1)+w3*U3(x3)+w5*U5(x5)									
U(x)=m*x+b									

Summary of Optimization Simulations									
	Thermal Flux Percentage of Total Flux	**Thermal Error**	**x1**	**U1**	**x3**	**U3**	**x5**	**U5**	**V**
Scenario 1 (3%, 1/16" B, 1/16" Cd)	0.00%	0.0000	2.93443E+12	0.10625	16.5978%	-0.65978	3%	0.8817	-0.0451
Scenario 2 (3%, 1/8" B, 1/16" Cd)	0.00%	0.0000	2.72520E+12	0.09076	10.2109%	-0.02109	3%	0.8817	0.2042
Scenario 3 (3%, 1/8" B, 1/32" Cd)	0.00%	0.0000	2.82303E+12	0.09800	10.0870%	-0.00870	3%	0.8817	0.2121
Scenario 4 (10%, 1/16" B, 1/16" Cd)	0.00%	0.0000	3.46023E+12	0.14520	15.0525%	-0.50525	10%	0.5187	-0.0403
Scenario 5 (10%, 1/8" B, 1/32" Cd)	0.00%	0.0000	3.19482E+12	0.12554	10.7989%	-0.07989	10%	0.5187	0.1220
Scenario 6 (15%, 1/8" B, 1/16" Cd)	0.00%	0.0000	3.08373E+12	0.11731	10.3798%	-0.03798	15%	0.2593	0.0836
Scenario 7 (20%, 1/8" B, 1/16" Cd)	0.00%	0.0000	3.44490E+12	0.14407	9.9674%	0.00326	20%	0.0000	0.0589
Scenario 8 (3%, 3/16" B, 1/16" Cd)	0.00%	0.0000	2.50124E+12	0.07417	8.2970%	0.17030	3%	0.8817	0.2741
Scenario 9 (10%, 3/16" B, 1/16" Cd)	0.00%	0.0000	2.56031E+12	0.07854	8.9434%	0.10566	10%	0.5187	0.1774
Scenario 10 (15%, 3/16" B, 1/16" Cd)	0.00%	0.0000	2.75777E+12	0.09317	8.5472%	0.14528	15%	0.2593	0.1472
Scenario 11 (20%, 3/16" B, 1/16" Cd)	0.00%	0.0000	3.06357E+12	0.11582	8.7881%	0.12119	20%	0.0000	0.0948

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Enrichment (%)	3.0%	3.0%	3.0%	10.0%	10.0%	15.0%
Cadmium Thickness (in)	0.158750	0.158750	0.079375	0.158750	0.079375	0.158750
Boron Thickness (in)	0.158750	0.317500	0.317500	0.158750	0.317500	0.317500
GEOMETRY						
Inner aluminum inside radius (constant)	0.866950	0.866950	0.866950	0.866950	0.866950	0.866950
Aluminum thickness (constant)	0.162560	0.162560	0.162560	0.162560	0.162560	0.162560
Inner aluminum outside radius (constant)	1.029510	1.029510	1.029510	1.029510	1.029510	1.029510
Cadmium thickness (variable)	0.158750	0.158750	0.079375	0.158750	0.079375	0.158750
Cadmium outer radius (variable)	1.188260	1.188260	1.108885	1.188260	1.108885	1.188260
Aluminum thickness (constant)	0.162560	0.162560	0.162560	0.162560	0.162560	0.162560
Cd-B Al outer radius (variable)	1.350820	1.350820	1.271445	1.350820	1.271445	1.350820
Boron thickness (variable)	0.158750	0.317500	0.317500	0.158750	0.317500	0.317500
Boron outer radius (variable)	1.509570	1.668320	1.588945	1.509570	1.588945	1.668320
Aluminum thickness (constant)	0.162560	0.162560	0.162560	0.162560	0.162560	0.162560
B-U Al outer radius (variable)	1.672130	1.830880	1.751505	1.672130	1.751505	1.830880
Uranium thickness (variable)	0.546560	0.387810	0.467185	0.546560	0.467185	0.387810
Uranium outer radius (constant)	2.218690	2.218690	2.218690	2.218690	2.218690	2.218690
Aluminum thickness (constant)	0.162560	0.162560	0.162560	0.162560	0.162560	0.162560
Outer aluminum outer radius (constant)	2.381250	2.381250	2.381250	2.381250	2.381250	2.381250
WEIGHT FRACTIONS FOR U3O8						
Enrichment (Percent U-235)	3.00%	3.00%	3.00%	10.00%	10.00%	15.00%
U-235 Atomic Mass	235.043928	235.043928	235.043928	235.043928	235.043928	235.043928
Percent U-234	0.02670%	0.02670%	0.02670%	0.02670%	0.02670%	0.02670%
U-234 Atomic Mass	234.040950	234.040950	234.040950	234.040950	234.040950	234.040950
Percent U-236	0.01380%	0.01380%	0.01380%	0.01380%	0.01380%	0.01380%
U-236 Atomic Mass	236.045566	236.045566	236.045566	236.045566	236.045566	236.045566
Percent U-238	96.9595%	96.9595%	96.9595%	89.9595%	89.9595%	84.9595%
U-238 Atomic Mass	238.050787	238.050787	238.050787	238.050787	238.050787	238.050787
Oxygen Atomic Mass	15.994915	15.994915	15.994915	15.994915	15.994915	15.994915
Total Weight of U3O8	841.8370216	841.8370216	841.8370216	841.2055813	841.2055813	840.7545524
Oxygen Weight Fraction	0.15204843	0.15204843	0.15204843	0.15216257	0.15216257	0.15224419
U-234 Weight Fraction	0.00022269	0.00022269	0.00022269	0.00022285	0.00022285	0.00022297
U-235 Weight Fraction	0.02512832	0.02512832	0.02512832	0.08382395	0.08382395	0.12580338
U-236 Weight Fraction	0.00011608	0.00011608	0.00011608	0.00011617	0.00011617	0.00011623
U-238 Weight Fraction	0.82253280	0.82253280	0.82253280	0.76372281	0.76372281	0.72166160
TALLIES						
NPS from MCNP	4998192	5001751	4998401	4999519	4999936	5000762
Conversion to 950 kW	7.2042E+16	7.2042E+16	7.2042E+16	7.2042E+16	7.2042E+16	7.2042E+16
Tally 4 Thermal Tally (1/cm^2*s)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Tally 4 Thermal Error	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tally 4 Epithermal Tally (1/cm^2*s)	8.32028E-06	4.25822E-06	4.30813E-06	8.33909E-06	5.55424E-06	4.93406E-06
Tally 4 Epithermal Error	0.0984	0.1436	0.1416	0.0983	0.1190	0.1312
Tally 4 Fast Tally (1/cm^2*s)	4.06307E-05	3.82409E-05	3.96600E-05	4.89543E-05	4.41693E-05	4.25255E-05
Tally 4 Fast Error	0.0433	0.0484	0.0490	0.0438	0.0467	0.0487
Tally 4 Total Tally (1/cm^2*s)	4.89510E-05	4.24991E-05	4.39682E-05	5.72933E-05	4.97236E-05	4.74596E-05
Tally 4 Total Error	0.0433	0.0459	0.0463	0.0401	0.0436	0.0458
Tally 14 Thermal Tally (1/cm^2*s)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Tally 14 Thermal Error	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tally 14 Epithermal Tally (1/cm^2*s)	8.21224E-06	4.16678E-06	4.60273E-06	8.57025E-06	5.07953E-06	5.00855E-06
Tally 14 Epithermal Error	0.1026	0.1454	0.1348	0.1009	0.1228	0.1232
Tally 14 Fast Tally (1/cm^2*s)	4.17696E-05	3.66251E-05	3.94192E-05	4.84867E-05	4.51190E-05	4.24000E-05
Tally 14 Fast Error	0.0430	0.0488	0.0482	0.0442	0.0474	0.0476
Tally 14 Total Tally (1/cm^2*s)	4.99818E-05	4.07919E-05	4.40220E-05	5.70569E-05	5.01985E-05	4.74085E-05
Tally 14 Total Error	0.0430	0.0464	0.0455	0.0406	0.0444	0.0445
Tally 24 Thermal Tally (1/cm^2*s)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Tally 24 Thermal Error	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tally 24 Epithermal Tally (1/cm^2*s)	7.78570E-06	4.48050E-06	4.27752E-06	8.62349E-06	5.47241E-06	4.93026E-06
Tally 24 Epithermal Error	0.0976	0.1378	0.1363	0.1015	0.1207	0.1363
Tally 24 Fast Tally (1/cm^2*s)	3.97962E-05	3.86178E-05	3.84784E-05	4.66511E-05	4.37516E-05	4.34882E-05
Tally 24 Fast Error	0.0472	0.0501	0.0498	0.0453	0.0472	0.0468
Tally 24 Total Tally (1/cm^2*s)	4.75819E-05	4.30983E-05	4.27559E-05	5.52746E-05	4.92241E-05	4.84185E-05
Tally 24 Total Error	0.0427	0.0471	0.0468	0.0414	0.0441	0.0443
Average Thermal Tally (1/cm^2*s)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
Average Epithermal Tally (1/cm^2*s)	8.10607E-06	4.30183E-06	4.39613E-06	8.51094E-06	5.36873E-06	4.95762E-06
Average Fast Tally (1/cm^2*s)	4.07322E-05	3.78279E-05	3.91859E-05	4.80307E-05	4.43466E-05	4.28046E-05
Average Total Tally (1/cm^2*s)	4.88382E-05	4.21298E-05	4.35820E-05	5.65416E-05	4.97154E-05	4.77622E-05
Average Thermal Flux at 950 kW (n/cm^2*s)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
Average Thermal Error	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Average Epithermal Flux at 950 kW (n/cm^2*s)	5.83978E+11	3.09913E+11	3.16706E+11	6.13146E+11	3.86774E+11	3.57157E+11
Average Epithermal Error	0.0995	0.1423	0.1376	0.1002	0.1208	0.1302
Average Fast Flux at 950 kW (n/cm^2*s)	2.93443E+12	2.72520E+12	2.82303E+12	3.46023E+12	3.19482E+12	3.08373E+12
Average Fast Error	0.0445	0.0491	0.0490	0.0444	0.0471	0.0477
Average Total Flux at 950 kW (n/cm^2*s)	3.51840E+12	3.03511E+12	3.13974E+12	4.07337E+12	3.58160E+12	3.44089E+12
Average Total Error	0.0430	0.0465	0.0462	0.0407	0.0440	0.0449
Thermal Flux Percentage of Total Flux	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Epithermal Flux Percentage of Total Flux	16.6%	10.2%	10.1%	15.1%	10.8%	10.4%
Fast Flux Percentage of Total Flux	83.4%	89.8%	89.9%	84.9%	89.2%	89.6%

	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11
Enrichment (%)	20.0%	3.0%	10.0%	15.0%	20.0%
Cadmium Thickness (in)	0.158750	0.158750	0.158750	0.158750	0.158750
Boron Thickness (in)	0.317500	0.476250	0.476250	0.476250	0.476250
GEOMETRY					
Inner aluminum inside radius (constant)	0.866950	0.866950	0.866950	0.866950	0.866950
Aluminum thickness (constant)	0.162560	0.162560	0.162560	0.162560	0.162560
Inner aluminum outside radius (constant)	1.029510	1.029510	1.029510	1.029510	1.029510
Cadmium thickness (variable)	0.158750	0.158750	0.158750	0.158750	0.158750
Cadmium outer radius (variable)	1.188260	1.188260	1.188260	1.188260	1.188260
Aluminum thickness (constant)	0.162560	0.162560	0.162560	0.162560	0.162560
Cd-B Al outer radius (variable)	1.350820	1.350820	1.350820	1.350820	1.350820
Boron thickness (variable)	0.317500	0.476250	0.476250	0.476250	0.476250
Boron outer radius (variable)	1.668320	1.827070	1.827070	1.827070	1.827070
Aluminum thickness (constant)	0.162560	0.162560	0.162560	0.162560	0.162560
B-U Al outer radius (variable)	1.830880	1.989630	1.989630	1.989630	1.989630
Uranium thickness (variable)	0.387810	0.229060	0.229060	0.229060	0.229060
Uranium outer radius (constant)	2.218690	2.218690	2.218690	2.218690	2.218690
Aluminum thickness (constant)	0.162560	0.162560	0.162560	0.162560	0.162560
Outer aluminum outer radius (constant)	2.381250	2.381250	2.381250	2.381250	2.381250
WEIGHT FRACTIONS FOR U3O8					
Enrichment (Percent U-235)	20.00%	3.00%	10.00%	15.00%	20.00%
U-235 Atomic Mass	235.043928	235.043928	235.043928	235.043928	235.043928
Percent U-234	0.02670%	0.02670%	0.02670%	0.02670%	0.02670%
U-234 Atomic Mass	234.040950	234.040950	234.040950	234.040950	234.040950
Percent U-236	0.01380%	0.01380%	0.01380%	0.01380%	0.01380%
U-236 Atomic Mass	236.045566	236.045566	236.045566	236.045566	236.045566
Percent U-238	79.9595%	96.9595%	89.9595%	84.9595%	79.9595%
U-238 Atomic Mass	238.050787	238.050787	238.050787	238.050787	238.050787
Oxygen Atomic Mass	15.994915	15.994915	15.994915	15.994915	15.994915
Total Weight of U3O8	840.3035236	841.8370216	841.2055813	840.7545524	840.3035236
Oxygen Weight Fraction	0.15232591	0.15204843	0.15216257	0.15224419	0.15232591
U-234 Weight Fraction	0.00022309	0.00022269	0.00022285	0.00022297	0.00022309
U-235 Weight Fraction	0.16782788	0.02512832	0.08382395	0.12580338	0.16782788
U-236 Weight Fraction	0.00011629	0.00011608	0.00011617	0.00011623	0.00011629
U-238 Weight Fraction	0.67955523	0.82253280	0.76372281	0.72166160	0.67955523
TALLIES					
NPS from MCNP	5003929	5000962	5002018	4997956	4996302
Conversion to 950 kW	7.2042E+16	7.2042E+16	7.2042E+16	7.2042E+16	7.2042E+16
Tally 4 Thermal Tally (1/cm^2*s)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Tally 4 Thermal Error	0.0000	0.0000	0.0000	0.0000	0.0000
Tally 4 Epithermal Tally (1/cm^2*s)	5.85013E-06	2.54034E-06	3.62799E-06	3.74166E-06	4.41476E-06
Tally 4 Epithermal Error	0.1207	0.1674	0.1551	0.1568	0.1481
Tally 4 Fast Tally (1/cm^2*s)	4.66793E-05	3.46358E-05	3.67300E-05	3.70715E-05	4.29275E-05
Tally 4 Fast Error	0.0440	0.0509	0.0512	0.0486	0.0502
Tally 4 Total Tally (1/cm^2*s)	5.25295E-05	3.71761E-05	4.03580E-05	4.08132E-05	4.73423E-05
Tally 4 Total Error	0.0414	0.0487	0.0487	0.0465	0.0476
Tally 14 Thermal Tally (1/cm^2*s)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Tally 14 Thermal Error	0.0000	0.0000	0.0000	0.0000	0.0000
Tally 14 Epithermal Tally (1/cm^2*s)	5.09552E-06	3.48539E-06	3.12022E-06	4.08226E-06	3.88561E-06
Tally 14 Epithermal Error	0.1326	0.1634	0.1523	0.1432	0.1435
Tally 14 Fast Tally (1/cm^2*s)	4.76868E-05	3.52559E-05	3.45429E-05	4.06941E-05	4.32640E-05
Tally 14 Fast Error	0.0439	0.0516	0.0531	0.0478	0.0476
Tally 14 Total Tally (1/cm^2*s)	5.27824E-05	3.87413E-05	3.76631E-05	4.47763E-05	4.71496E-05
Tally 14 Total Error	0.0417	0.0492	0.0503	0.0454	0.0453
Tally 24 Thermal Tally (1/cm^2*s)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Tally 24 Thermal Error	0.0000	0.0000	0.0000	0.0000	0.0000
Tally 24 Epithermal Tally (1/cm^2*s)	4.93591E-06	3.39809E-06	3.72356E-06	2.90912E-06	3.99116E-06
Tally 24 Epithermal Error	0.1324	0.1506	0.1522	0.1666	0.1629
Tally 24 Fast Tally (1/cm^2*s)	4.90875E-05	3.42659E-05	3.53444E-05	3.70746E-05	4.13826E-05
Tally 24 Fast Error	0.0462	0.0505	0.0512	0.049	0.0486
Tally 24 Total Tally (1/cm^2*s)	5.40235E-05	3.76640E-05	3.90680E-05	3.99837E-05	4.53738E-05
Tally 24 Total Error	0.0436	0.0479	0.0485	0.0471	0.0466
Average Thermal Tally (1/cm^2*s)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
Average Epithermal Tally (1/cm^2*s)	5.29385E-06	3.14127E-06	3.49059E-06	3.57768E-06	4.09718E-06
Average Fast Tally (1/cm^2*s)	4.78179E-05	3.47192E-05	3.55391E-05	3.82801E-05	4.25247E-05
Average Total Tally (1/cm^2*s)	5.31118E-05	3.78605E-05	3.90297E-05	4.18577E-05	4.66219E-05
Average Thermal Flux at 950 kW (n/cm^2*s)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
Average Thermal Error	0.0000	0.0000	0.0000	0.0000	0.0000
Average Epithermal Flux at 950 kW (n/cm^2*s)	3.81380E+11	2.26304E+11	2.51469E+11	2.57743E+11	2.95169E+11
Average Epithermal Error	0.1286	0.1605	0.1532	0.1555	0.1515
Average Fast Flux at 950 kW (n/cm^2*s)	3.44490E+12	2.50124E+12	2.56031E+12	2.75777E+12	3.06357E+12
Average Fast Error	0.0447	0.0510	0.0518	0.0485	0.0488
Average Total Flux at 950 kW (n/cm^2*s)	3.82628E+12	2.72754E+12	2.81178E+12	3.01552E+12	3.35874E+12
Average Total Error	0.0422	0.0486	0.0492	0.0463	0.0465
Thermal Flux Percentage of Total Flux	0.0%	0.0%	0.0%	0.0%	0.0%
Epithermal Flux Percentage of Total Flux	10.0%	8.3%	8.9%	8.5%	8.8%
Fast Flux Percentage of Total Flux	90.0%	91.7%	91.1%	91.5%	91.2%

Appendix 4: Results from Final Simulations

	Final Results - First Simulation							
File Name	**3L03L Tally 4**		**3L03L Tally 14**		**3L03L Tally 24**		**3L03L Tally**	
Enrichment (%)	3.0%		3.0%		3.0%		3.0%	
Cadmium Thickness (in)	0.158750		0.158750		0.158750		0.158750	
Boron Thickness (in)	0.476250		0.476250		0.476250		0.476250	
GEOMETRY								
Inner aluminum inside radius (constant)	0.866950		0.866950		0.866950		0.866950	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
Inner aluminum outside radius (constant)	1.029510		1.029510		1.029510		1.029510	
Cadmium thickness (variable)	0.158750		0.158750		0.158750		0.158750	
Cadmium outer radius (variable)	1.188260		1.188260		1.188260		1.188260	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
Cd-B Al outer radius (variable)	1.350820		1.350820		1.350820		1.350820	
Boron thickness (variable)	0.476250		0.476250		0.476250		0.476250	
Boron outer radius (variable)	1.827070		1.827070		1.827070		1.827070	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
B-U Al outer radius (variable)	1.989630		1.989630		1.989630		1.989630	
Uranium thickness (variable)	0.229060		0.229060		0.229060		0.229060	
Uranium outer radius (constant)	2.218690		2.218690		2.218690		2.218690	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
Outer aluminum outer radius (constant)	2.381250		2.381250		2.381250		2.381250	
WEIGHT FRACTIONS FOR U3O8								
Enrichment (Percent U-235)	0.030000		0.030000		0.030000		0.030000	
U-235 Atomic Mass	235.043928		235.043928		235.043928		235.043928	
Percent U-234	0.000267		0.000267		0.000267		0.000267	
U-234 Atomic Mass	234.040950		234.040950		234.040950		234.040950	
Percent U-236	0.000138		0.000138		0.000138		0.000138	
U-236 Atomic Mass	236.045566		236.045566		236.045566		236.045566	
Percent U-238	0.969595		0.969595		0.969595		0.969595	
U-238 Atomic Mass	238.050787		238.050787		238.050787		238.050787	
Oxygen Atomic Mass	15.994915		15.994915		15.994915		15.994915	
Total Weight of U3O8	841.837022		841.837022		841.837022		841.837022	
Oxygen Weight Fraction	0.152048		0.152048		0.152048		0.152048	
U-234 Weight Fraction	0.000223		0.000223		0.000223		0.000223	
U-235 Weight Fraction	0.025128		0.025128		0.025128		0.025128	
U-236 Weight Fraction	0.000116		0.000116		0.000116		0.000116	
U-238 Weight Fraction	0.822533		0.822533		0.822533		0.822533	
TALLIES								
NPS from MCNP	49997579		49997579		49997579		49997579	
Conversion to 950 kW	-		-		-		-	
	Tally	Error	Tally	Error	Tally	Error	Tally	Error
1.0000E-11	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.0000E-09	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.5000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.5000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.5000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
4.2000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.8000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
6.7000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
8.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.0000E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.5200E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.5100E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
4.1400E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
6.8300E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.1250E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.8550E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.0590E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.0430E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
8.3150E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.3710E-05	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.2600E-05	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.7270E-05	0.00000E+00	0.0000	1.15709E-08	0.7836	1.20511E-08	0.9687	7.8740E-09	0.5841
6.1440E-05	8.07010E-09	0.8158	1.38814E-08	0.8755	4.99859E-09	1.0000	8.9834E-09	0.8971
1.0130E-04	1.65264E-09	1.0000	1.16293E-08	0.7553	9.25633E-09	1.0000	7.5128E-09	0.9184
1.6700E-04	6.38209E-08	0.3248	3.64684E-08	0.3831	7.66137E-08	0.2967	5.8968E-08	0.3349
2.7540E-04	8.93833E-08	0.3123	7.57676E-08	0.3147	5.99092E-08	0.3716	7.5020E-08	0.3329
4.5400E-04	1.49407E-07	0.2365	2.13016E-07	0.1932	1.21517E-07	0.2375	1.6131E-07	0.2224
7.4850E-04	2.41733E-07	0.1763	3.42808E-07	0.1816	3.09619E-07	0.1693	2.9805E-07	0.1757
1.2340E-03	4.09602E-07	0.1432	3.51393E-07	0.1566	4.69352E-07	0.1347	4.1012E-07	0.1448
2.0350E-03	3.46981E-07	0.1427	3.96018E-07	0.1375	3.42341E-07	0.1446	3.6178E-07	0.1416
2.4040E-03	1.73835E-07	0.2140	1.80138E-07	0.2174	1.86349E-07	0.2039	1.8011E-07	0.2118
2.8400E-03	1.45453E-07	0.2175	2.19939E-07	0.1982	2.17785E-07	0.1971	1.9439E-07	0.2043
3.3550E-03	1.55155E-07	0.2263	2.16126E-07	0.1876	2.03991E-07	0.2174	1.9176E-07	0.2104
5.5310E-03	6.12312E-07	0.1216	5.19328E-07	0.1272	6.50393E-07	0.1223	5.9401E-07	0.1237
9.1190E-03	7.41778E-07	0.1038	7.29739E-07	0.1027	7.88445E-07	0.1149	7.5332E-07	0.1071
1.5030E-02	8.82901E-07	0.0984	8.11328E-07	0.0943	1.02887E-06	0.0893	9.0770E-07	0.0940
1.9890E-02	5.61441E-07	0.1207	4.89966E-07	0.1277	4.27449E-07	0.1449	4.9295E-07	0.1311
2.5540E-02	4.12630E-07	0.1513	3.86576E-07	0.1485	4.28532E-07	0.1350	4.0925E-07	0.1449
4.0870E-02	9.49162E-07	0.0947	9.57362E-07	0.0955	1.03240E-06	0.1023	9.7964E-07	0.0975
6.7380E-02	1.49954E-06	0.0860	1.17872E-06	0.0838	1.22230E-06	0.0868	1.3002E-06	0.0855
1.1110E-01	1.53622E-06	0.0774	1.57750E-06	0.0798	1.55935E-06	0.0768	1.5577E-06	0.0780
1.8320E-01	1.77595E-06	0.0689	2.09573E-06	0.0687	1.98052E-06	0.0649	1.9507E-06	0.0675
3.0200E-01	2.56765E-06	0.0611	2.53012E-06	0.0628	2.64106E-06	0.0576	2.5796E-06	0.0605
3.8870E-01	1.75740E-06	0.0726	1.46767E-06	0.0814	1.52102E-06	0.0758	1.5820E-06	0.0766
4.9790E-01	1.59979E-06	0.0767	1.74052E-06	0.0732	1.69727E-06	0.0789	1.6792E-06	0.0763
6.3928E-01	1.86861E-06	0.0738	1.98443E-06	0.0686	1.88961E-06	0.0678	1.9142E-06	0.0701
8.2085E-01	2.35339E-06	0.0676	2.19556E-06	0.0659	2.12051E-06	0.0666	2.2232E-06	0.0667
1.1080E+00	2.55096E-06	0.0613	3.03874E-06	0.0576	2.82005E-06	0.0584	2.8033E-06	0.0591
1.3534E+00	1.86746E-06	0.0700	1.82137E-06	0.0740	1.72581E-06	0.0755	1.8049E-06	0.0732
1.7377E+00	2.47217E-06	0.0612	2.62174E-06	0.0577	2.67681E-06	0.0583	2.5902E-06	0.0591
2.2313E+00	2.40782E-06	0.0645	2.46351E-06	0.0618	2.39114E-06	0.0612	2.4208E-06	0.0625
2.8651E+00	2.42916E-06	0.0605	2.38866E-06	0.0638	2.49319E-06	0.0606	2.4370E-06	0.0616
3.6788E+00	1.76053E-06	0.0696	1.68123E-06	0.0708	1.85964E-06	0.0696	1.7671E-06	0.0700
4.9658E+00	1.55681E-06	0.0737	1.50885E-06	0.0790	1.54915E-06	0.0757	1.5383E-06	0.0761
6.0650E+00	6.72946E-07	0.1206	7.19706E-07	0.1093	5.33295E-07	0.1238	6.4198E-07	0.1179
1.0000E+01	4.39554E-07	0.1362	4.98854E-07	0.1310	4.58264E-07	0.1382	4.6556E-07	0.1351
1.4918E+01	3.10401E-08	0.5038	3.90343E-08	0.4302	3.46090E-08	0.4579	3.4894E-08	0.4640
1.6905E+01	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.0000E+01	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.5000E+01	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
Total	3.70923E-05	0.0159	3.75150E-05	0.0158	3.75435E-05	0.0157	3.7384E-05	0.0158

	Final Results - Second Simulation							
File Name	3L03L2 Tally 4		3L03L2 Tally 14		3L03L2 Tally 24		3L03L2 Tally	
Enrichment (%)	3.0%		3.0%		3.0%		3.0%	
Cadmium Thickness (in)	0.158750		0.158750		0.158750		0.158750	
Boron Thickness (in)	0.476250		0.476250		0.476250		0.476250	
GEOMETRY								
Inner aluminum inside radius (constant)	0.866950		0.866950		0.866950		0.866950	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
Inner aluminum outside radius (constant)	1.029510		1.029510		1.029510		1.029510	
Cadmium thickness (variable)	0.158750		0.158750		0.158750		0.158750	
Cadmium outer radius (variable)	1.188260		1.188260		1.188260		1.188260	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
Cd-B Al outer radius (variable)	1.350820		1.350820		1.350820		1.350820	
Boron thickness (variable)	0.476250		0.476250		0.476250		0.476250	
Boron outer radius (variable)	1.827070		1.827070		1.827070		1.827070	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
B-U Al outer radius (variable)	1.989630		1.989630		1.989630		1.989630	
Uranium thickness (variable)	0.229060		0.229060		0.229060		0.229060	
Uranium outer radius (constant)	2.218690		2.218690		2.218690		2.218690	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
Outer aluminum outer radius (constant)	2.381250		2.381250		2.381250		2.381250	
WEIGHT FRACTIONS FOR U3O8								
Enrichment (Percent U-235)	0.030000		0.030000		0.030000		0.030000	
U-235 Atomic Mass	235.043928		235.043928		235.043928		235.043928	
Percent U-234	0.000267		0.000267		0.000267		0.000267	
U-234 Atomic Mass	234.040950		234.040950		234.040950		234.040950	
Percent U-236	0.000138		0.000138		0.000138		0.000138	
U-236 Atomic Mass	236.045566		236.045566		236.045566		236.045566	
Percent U-238	0.969595		0.969595		0.969595		0.969595	
U-238 Atomic Mass	238.050787		238.050787		238.050787		238.050787	
Oxygen Atomic Mass	15.994915		15.994915		15.994915		15.994915	
Total Weight of U3O8	841.837022		841.837022		841.837022		841.837022	
Oxygen Weight Fraction	0.152048		0.152048		0.152048		0.152048	
U-234 Weight Fraction	0.000223		0.000223		0.000223		0.000223	
U-235 Weight Fraction	0.025128		0.025128		0.025128		0.025128	
U-236 Weight Fraction	0.000116		0.000116		0.000116		0.000116	
U-238 Weight Fraction	0.822533		0.822533		0.822533		0.822533	
TALLIES								
NPS from MCNP	49997579		49997579		49997579		49997579	
Conversion to 950 kW	-		-		-		-	
	Tally	Error	Tally	Error	Tally	Error	Tally	Error
1.0000E-11	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.0000E-09	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.5000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.5000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.5000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
4.2000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.8000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
6.7000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
8.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.0000E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.5200E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.5100E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
4.1400E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
6.8300E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.1250E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.8550E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.0590E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.0430E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
8.3150E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.3710E-05	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.2600E-05	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.7270E-05	6.26967E-09	1.0000	8.07344E-09	1.0000	2.47714E-08	0.5268	1.3038E-08	0.8423
6.1440E-05	1.03750E-08	0.7444	1.34250E-08	0.7096	1.02954E-08	0.8124	1.1365E-08	0.7555
1.0130E-04	2.54076E-08	0.5106	4.96673E-08	0.3963	4.79635E-08	0.3809	4.1013E-08	0.4293
1.6700E-04	5.91719E-08	0.3515	4.49513E-08	0.4532	7.10533E-08	0.3067	5.8392E-08	0.3705
2.7540E-04	8.21605E-08	0.2879	6.98542E-08	0.3062	7.03069E-08	0.2982	7.4107E-08	0.2974
4.5400E-04	2.22460E-07	0.2086	1.12917E-07	0.2468	2.08142E-07	0.2027	1.8117E-07	0.2194
7.4850E-04	2.43425E-07	0.1877	2.22700E-07	0.1844	2.93083E-07	0.1756	2.5307E-07	0.1826
1.2340E-03	3.33304E-07	0.1521	3.39871E-07	0.1639	3.20639E-07	0.1510	3.3127E-07	0.1557
2.0350E-03	3.59341E-07	0.1463	3.39905E-07	0.1527	4.00776E-07	0.1372	3.6667E-07	0.1454
2.4040E-03	1.93784E-07	0.2062	2.13351E-07	0.2018	2.08265E-07	0.1830	2.0513E-07	0.1970
2.8400E-03	1.87515E-07	0.2094	1.20815E-07	0.2631	1.36688E-07	0.2392	1.4834E-07	0.2372
3.3550E-03	2.09502E-07	0.1822	2.10569E-07	0.1930	2.49276E-07	0.1843	2.2312E-07	0.1865
5.5310E-03	6.81780E-07	0.1134	6.48496E-07	0.1169	5.74328E-07	0.1145	6.3487E-07	0.1149
9.1190E-03	6.00026E-07	0.1182	7.07340E-07	0.1163	6.28649E-07	0.1121	6.4534E-07	0.1155
1.5030E-02	7.12447E-07	0.1172	6.98778E-07	0.1123	6.16277E-07	0.1055	6.7583E-07	0.1117
1.9890E-02	5.05599E-07	0.1231	4.63342E-07	0.1331	5.24101E-07	0.1370	4.9768E-07	0.1311
2.5540E-02	5.04668E-07	0.1264	4.78102E-07	0.1252	5.57243E-07	0.1273	5.1334E-07	0.1263
4.0870E-02	8.78214E-07	0.1007	1.06713E-06	0.0925	9.53387E-07	0.0983	9.6624E-07	0.0972
6.7380E-02	1.10759E-06	0.0892	1.21223E-06	0.0826	1.42282E-06	0.0833	1.2475E-06	0.0850
1.1110E-01	1.58782E-06	0.0743	1.62404E-06	0.0772	1.66847E-06	0.0767	1.6268E-06	0.0761
1.8320E-01	1.89436E-06	0.0668	1.89913E-06	0.0680	2.02861E-06	0.0649	1.9407E-06	0.0666
3.0200E-01	2.37600E-06	0.0609	2.24175E-06	0.0634	2.78860E-06	0.0633	2.4688E-06	0.0625
3.8870E-01	1.54647E-06	0.0774	1.51764E-06	0.0760	1.71230E-06	0.0729	1.5921E-06	0.0754
4.9790E-01	1.58472E-06	0.0782	1.55348E-06	0.0764	1.61082E-06	0.0764	1.5830E-06	0.0770
6.3928E-01	2.01886E-06	0.0692	2.28154E-06	0.0657	2.02998E-06	0.0665	2.1101E-06	0.0671
8.2085E-01	2.33198E-06	0.0625	2.10671E-06	0.0652	2.40793E-06	0.0632	2.2822E-06	0.0636
1.1080E+00	2.60406E-06	0.0592	2.71833E-06	0.0615	2.78004E-06	0.0566	2.7008E-06	0.0591
1.3534E+00	1.84419E-06	0.0709	1.76086E-06	0.0727	1.79325E-06	0.0698	1.7994E-06	0.0711
1.7377E+00	2.40258E-06	0.0618	2.61977E-06	0.0582	2.68564E-06	0.0582	2.5693E-06	0.0594
2.2313E+00	2.38374E-06	0.0612	2.22953E-06	0.0639	2.70056E-06	0.0579	2.4379E-06	0.0610
2.8651E+00	2.19843E-06	0.0640	2.16616E-06	0.0661	2.23008E-06	0.0651	2.1982E-06	0.0651
3.6788E+00	1.68642E-06	0.0728	1.77467E-06	0.0717	1.72135E-06	0.0718	1.7275E-06	0.0721
4.9658E+00	1.37856E-06	0.0820	1.59369E-06	0.0764	1.49237E-06	0.0797	1.4882E-06	0.0794
6.0650E+00	5.73288E-07	0.1251	4.93853E-07	0.1327	6.15436E-07	0.1246	5.6086E-07	0.1275
1.0000E+01	4.03988E-07	0.1464	3.58713E-07	0.1460	4.61481E-07	0.1472	4.0806E-07	0.1465
1.4918E+01	3.52633E-08	0.4896	3.44127E-08	0.4593	3.23627E-08	0.4822	3.4013E-08	0.4770
1.6905E+01	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.0000E+01	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.5000E+01	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
Total	3.57738E-05	0.0159	3.59958E-05	0.0160	3.80773E-05	0.0156	3.6616E-05	0.0158

	Final Results - Third Simulation							
File Name	3L03L3 Tally 4		3L03L3 Tally 14		3L03L3 Tally 24		3L03L3 Tally	
Enrichment (%)	3.0%		3.0%		3.0%		3.0%	
Cadmium Thickness (in)	0.158750		0.158750		0.158750		0.158750	
Boron Thickness (in)	0.476250		0.476250		0.476250		0.476250	
GEOMETRY								
Inner aluminum inside radius (constant)	0.866950		0.866950		0.866950		0.866950	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
Inner aluminum outside radius (constant)	1.029510		1.029510		1.029510		1.029510	
Cadmium thickness (variable)	0.158750		0.158750		0.158750		0.158750	
Cadmium outer radius (variable)	1.188260		1.188260		1.188260		1.188260	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
Cd-B Al outer radius (variable)	1.350820		1.350820		1.350820		1.350820	
Boron thickness (variable)	0.476250		0.476250		0.476250		0.476250	
Boron outer radius (variable)	1.827070		1.827070		1.827070		1.827070	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
B-U Al outer radius (variable)	1.989630		1.989630		1.989630		1.989630	
Uranium thickness (variable)	0.229060		0.229060		0.229060		0.229060	
Uranium outer radius (constant)	2.218690		2.218690		2.218690		2.218690	
Aluminum thickness (constant)	0.162560		0.162560		0.162560		0.162560	
Outer aluminum outer radius (constant)	2.381250		2.381250		2.381250		2.381250	
WEIGHT FRACTIONS FOR U3O8								
Enrichment (Percent U-235)	0.030000		0.030000		0.030000		0.030000	
U-235 Atomic Mass	235.043928		235.043928		235.043928		235.043928	
Percent U-234	0.000267		0.000267		0.000267		0.000267	
U-234 Atomic Mass	234.040950		234.040950		234.040950		234.040950	
Percent U-236	0.000138		0.000138		0.000138		0.000138	
U-236 Atomic Mass	236.045566		236.045566		236.045566		236.045566	
Percent U-238	0.969595		0.969595		0.969595		0.969595	
U-238 Atomic Mass	238.050787		238.050787		238.050787		238.050787	
Oxygen Atomic Mass	15.994915		15.994915		15.994915		15.994915	
Total Weight of U3O8	841.837022		841.837022		841.837022		841.837022	
Oxygen Weight Fraction	0.152048		0.152048		0.152048		0.152048	
U-234 Weight Fraction	0.000223		0.000223		0.000223		0.000223	
U-235 Weight Fraction	0.025128		0.025128		0.025128		0.025128	
U-236 Weight Fraction	0.000116		0.000116		0.000116		0.000116	
U-238 Weight Fraction	0.822533		0.822533		0.822533		0.822533	
TALLIES								
NPS from MCNP	49997579		49997579		49997579		49997579	
Conversion to 950 kW	-		-		-		-	
	Tally	Error	Tally	Error	Tally	Error	Tally	Error
1.0000E-11	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.0000E-09	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.5000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.5000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.5000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
4.2000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.8000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
6.7000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
8.0000E-08	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.0000E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.5200E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.5100E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
4.1400E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
6.8300E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.1250E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.8550E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.0590E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
5.0430E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
8.3150E-06	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
1.3710E-05	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.2600E-05	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
3.7270E-05	0.00000E+00	0.0000	9.65741E-09	1.0000	5.28567E-09	1.0000	4.9810E-09	0.6667
6.1440E-05	5.44896E-09	0.9370	1.43854E-08	0.7756	8.44597E-09	0.7220	9.4268E-09	0.8115
1.0130E-04	2.68427E-08	0.6330	3.04748E-08	0.5425	1.60356E-08	0.6320	2.4451E-08	0.6025
1.6700E-04	6.69988E-08	0.3430	7.62476E-08	0.3079	5.59834E-08	0.3666	6.6410E-08	0.3392
2.7540E-04	1.07318E-07	0.2690	7.58794E-08	0.3043	1.18372E-07	0.2662	1.0052E-07	0.2798
4.5400E-04	1.75374E-07	0.2119	1.95783E-07	0.2003	1.86536E-07	0.2050	1.8590E-07	0.2057
7.4850E-04	2.17071E-07	0.1825	2.03887E-07	0.1886	2.03398E-07	0.2030	2.0812E-07	0.1914
1.2340E-03	3.56755E-07	0.1540	3.06058E-07	0.1599	3.26450E-07	0.1530	3.2975E-07	0.1556
2.0350E-03	3.90296E-07	0.1425	3.51581E-07	0.1419	4.11683E-07	0.1404	3.8452E-07	0.1416
2.4040E-03	4.69263E-08	0.3253	9.37313E-08	0.3031	6.24081E-08	0.3612	6.7689E-08	0.3299
2.8400E-03	2.35628E-07	0.1894	1.94294E-07	0.2094	1.44146E-07	0.2118	1.9136E-07	0.2035
3.3550E-03	1.86162E-07	0.2289	1.70227E-07	0.2215	2.49175E-07	0.1991	2.0185E-07	0.2165
5.5310E-03	4.74101E-07	0.1255	5.65442E-07	0.1189	6.20073E-07	0.1145	5.5321E-07	0.1196
9.1190E-03	6.71246E-07	0.1095	7.78061E-07	0.1157	7.21375E-07	0.1155	7.2356E-07	0.1136
1.5030E-02	7.22000E-07	0.1055	6.84969E-07	0.1028	7.51288E-07	0.1038	7.1942E-07	0.1040
1.9890E-02	5.05320E-07	0.1235	4.31303E-07	0.1344	5.10435E-07	0.1269	4.8235E-07	0.1283
2.5540E-02	4.64445E-07	0.1318	4.70308E-07	0.1343	5.15442E-07	0.1263	4.8340E-07	0.1308
4.0870E-02	9.43256E-07	0.0951	9.88404E-07	0.0955	8.74389E-07	0.0958	9.3535E-07	0.0955
6.7380E-02	1.02214E-06	0.0873	1.19512E-06	0.0809	1.28401E-06	0.0875	1.1671E-06	0.0852
1.1110E-01	1.56987E-06	0.0742	1.58880E-06	0.0737	1.56746E-06	0.0744	1.5754E-06	0.0741
1.8320E-01	1.86828E-06	0.0689	1.72174E-06	0.0730	1.80138E-06	0.0695	1.7971E-06	0.0705
3.0200E-01	2.55993E-06	0.0590	2.70515E-06	0.0583	2.46636E-06	0.0590	2.5771E-06	0.0588
3.8870E-01	1.63386E-06	0.0763	1.31098E-06	0.0789	1.40861E-06	0.0789	1.4512E-06	0.0780
4.9790E-01	1.51697E-06	0.0801	1.55966E-06	0.0789	1.47753E-06	0.0795	1.5181E-06	0.0795
6.3928E-01	2.13617E-06	0.0694	2.05958E-06	0.0683	1.95641E-06	0.0671	2.0507E-06	0.0683
8.2085E-01	2.47293E-06	0.0629	2.11121E-06	0.0635	2.36952E-06	0.0624	2.3179E-06	0.0629
1.1080E+00	2.57322E-06	0.0612	2.68805E-06	0.0641	2.59438E-06	0.0624	2.6186E-06	0.0626
1.3534E+00	1.89001E-06	0.0694	1.84605E-06	0.0736	1.91800E-06	0.0698	1.8847E-06	0.0709
1.7377E+00	2.56452E-06	0.0596	2.59454E-06	0.0613	2.58451E-06	0.0581	2.5812E-06	0.0597
2.2313E+00	2.57898E-06	0.0583	2.59447E-06	0.0589	2.73785E-06	0.0586	2.6371E-06	0.0586
2.8651E+00	2.09116E-06	0.0684	2.32729E-06	0.0635	2.30690E-06	0.0618	2.2418E-06	0.0646
3.6788E+00	1.82352E-06	0.0746	1.54842E-06	0.0769	1.74840E-06	0.0724	1.7068E-06	0.0746
4.9658E+00	1.39177E-06	0.0784	1.43853E-06	0.0813	1.40701E-06	0.0758	1.4124E-06	0.0785
6.0650E+00	7.38790E-07	0.1113	6.84095E-07	0.1104	5.94839E-07	0.1214	6.7257E-07	0.1144
1.0000E+01	5.05600E-07	0.1308	4.49378E-07	0.1341	5.90985E-07	0.1207	5.1532E-07	0.1285
1.4918E+01	1.88429E-08	0.6478	0.00000E+00	0.0000	3.51405E-08	0.4764	1.7994E-08	0.3747
1.6905E+01	0.00000E+00	0.0000	0.00000E+00	0.0000	9.85624E-09	1.0000	3.2854E-09	0.3333
2.0000E+01	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
2.5000E+01	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.0000E+00	0.0000
Total	3.65518E-05	0.0159	3.60638E-05	0.0160	3.66401E-05	0.0157	3.6419E-05	0.0159

	Final Results			
File Name	Total			
Enrichment (%)	3.0%			
Cadmium Thickness (in)	0.158750			
Boron Thickness (in)	0.476250			
GEOMETRY				
Inner aluminum inside radius (constant)	0.866950			
Aluminum thickness (constant)	0.162560			
Inner aluminum outside radius (constant)	1.029510			
Cadmium thickness (variable)	0.158750			
Cadmium outer radius (variable)	1.188260			
Aluminum thickness (constant)	0.162560			
Cd-B Al outer radius (variable)	1.350820			
Boron thickness (variable)	0.476250			
Boron outer radius (variable)	1.827070			
Aluminum thickness (constant)	0.162560			
B-U Al outer radius (variable)	1.989630			
Uranium thickness (variable)	0.229060			
Uranium outer radius (constant)	2.218690			
Aluminum thickness (constant)	0.162560			
Outer aluminum outer radius (constant)	2.381250			
WEIGHT FRACTIONS FOR U3O8				
Enrichment (Percent U-235)	0.030000			
U-235 Atomic Mass	235.043928			
Percent U-234	0.000267			
U-234 Atomic Mass	234.040950			
Percent U-236	0.000138			
U-236 Atomic Mass	236.045566			
Percent U-238	0.969595			
U-238 Atomic Mass	238.050787			
Oxygen Atomic Mass	15.994915			
Total Weight of U3O8	841.837022			
Oxygen Weight Fraction	0.152048			
U-234 Weight Fraction	0.000223			
U-235 Weight Fraction	0.025128			
U-236 Weight Fraction	0.000116			
U-238 Weight Fraction	0.822533			
TALLIES				
NPS from MCNP	49997579			
Conversion to 950 kW	7.2042E+16			
	Tally	Flux at 950 KW (n/cm^2*s)	Error	Absolute Error
1.0000E-11	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
5.0000E-09	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
1.0000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
1.5000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
2.0000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
2.5000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
3.0000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
3.5000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
4.2000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
5.0000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
5.8000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
6.7000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
8.0000E-08	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
1.0000E-07	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
1.5200E-07	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
2.5100E-07	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
4.1400E-07	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
6.8300E-07	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
1.1250E-06	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
1.8550E-06	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
3.0590E-06	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
5.0430E-06	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
8.3150E-06	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
1.3710E-05	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
2.2600E-05	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
3.7270E-05	8.6311E-09	6.2180E+08	0.3280	2.0394E+08
6.1440E-05	9.9251E-09	7.1502E+08	0.5500	3.9326E+08
1.0130E-04	2.4326E-08	1.7525E+09	0.2375	4.1627E+08
1.6700E-04	6.1257E-08	4.4130E+09	0.0421	1.8568E+08
2.7540E-04	8.3217E-08	5.9951E+09	0.0277	1.6609E+08
4.5400E-04	1.7613E-07	1.2689E+10	0.0100	1.2736E+08
7.4850E-04	2.5308E-07	1.8232E+10	0.0061	1.1194E+08
1.2340E-03	3.5705E-07	2.5722E+10	0.0035	9.0256E+07
2.0350E-03	3.7099E-07	2.6727E+10	0.0029	7.7918E+07
2.4040E-03	1.5098E-07	1.0877E+10	0.0138	1.4968E+08
2.8400E-03	1.7803E-07	1.2826E+10	0.0099	1.2650E+08
3.3550E-03	2.0558E-07	1.4810E+10	0.0085	1.2584E+08
5.5310E-03	5.9403E-07	4.2795E+10	0.0017	7.2788E+07
9.1190E-03	7.0741E-07	5.0963E+10	0.0014	7.1637E+07
1.5030E-02	7.6765E-07	5.5303E+10	0.0011	6.0391E+07
1.9890E-02	4.9100E-07	3.5372E+10	0.0022	7.7960E+07
2.5540E-02	4.6866E-07	3.3763E+10	0.0024	8.0840E+07
4.0870E-02	9.6041E-07	6.9190E+10	0.0009	6.2577E+07
6.7380E-02	1.2383E-06	8.9208E+10	0.0006	5.5301E+07
1.1110E-01	1.5866E-06	1.1430E+11	0.0004	5.0253E+07
1.8320E-01	1.8962E-06	1.3661E+11	0.0003	4.3253E+07
3.0200E-01	2.5418E-06	1.8312E+11	0.0002	4.0713E+07
3.8870E-01	1.5418E-06	1.1107E+11	0.0005	5.0082E+07
4.9790E-01	1.5934E-06	1.1479E+11	0.0005	5.3593E+07
6.3928E-01	2.0250E-06	1.4589E+11	0.0003	4.6846E+07
8.2085E-01	2.2744E-06	1.6385E+11	0.0003	4.3767E+07
1.1080E+00	2.7075E-06	1.9506E+11	0.0002	4.2626E+07
1.3534E+00	1.8297E-06	1.3181E+11	0.0004	4.8663E+07
1.7377E+00	2.5803E-06	1.8589E+11	0.0002	3.8914E+07
2.2313E+00	2.4986E-06	1.8001E+11	0.0002	4.0216E+07
2.8651E+00	2.2923E-06	1.6514E+11	0.0003	4.2761E+07
3.6788E+00	1.7338E-06	1.2491E+11	0.0004	4.7049E+07
4.9658E+00	1.4796E-06	1.0660E+11	0.0005	5.0562E+07
6.0650E+00	6.2514E-07	4.5036E+10	0.0017	7.7406E+07
1.0000E+01	4.6298E-07	3.3354E+10	0.0025	8.4891E+07
1.4918E+01	2.8967E-08	2.0869E+09	0.0829	1.7308E+08
1.6905E+01	1.0951E-09	7.8896E+07	0.0000	0.0000E+00
2.0000E+01	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
2.5000E+01	0.0000E+00	0.0000E+00	0.0000	0.0000E+00
Total	3.6806E-05	2.6516E+12	0.0000	1.0525E+07

Final Results Summary		
Energy Range	Flux at 950 KW (n/cm^2*s)	Percentage of Total Flux
Thermal	0.0000E+00	0.000%
Epithermal	2.2914E+11	8.642%
Fast	2.4224E+12	91.358%
Total	2.6516E+12	

Appendix 5: MCNP Input File for Final Simulations

```
c 1/15/16 Core Shuffle at 299.868 MWD
c Note: Densities in cell cards, negative means g/cm3, positive means atoms/barn-cm
c **************************** BEGIN CELLS ********************************
c VOID
1101    0  (1:5:-2)
c Reflector Canister
1102    2 -1.0 (202:204) 403 -5 -1 $ water over reflector
1103    2 -1.0 (202:204) -418 2 -5 $ water under reflector
c Hexagonal Shroud
1104    6 -2.7 (-201 202:-203 204) -201 -203 -403 418  $ hex wall
1105    8 -0.001225 (201:203) -320 -403 409  $ Hex to RSR level, air
                    1341 1342 1343 1344 1345 1346 1347 1348 1349 1350
                    1351 1352 1353 1354 1355 1356 1357 1358 1359 1360
                    1361 1362 1363 1364 1365 1366 1367 1368 1369 1370
                    1371 1372 1373 1374 1375 1376 1377 1378 1379 1380
1106    5 -1.6 -6 ((320 -403 409):(418 (201:203) -409)) 502 # $
            (-507 203.6)#(-504 -505)#(-509 203.4)
c POOL # $ pool water, not beam ports
1107    2 -1.0 -403 418 6 -5 502#(-507 203.6)#(-504 -505)#(-509 203.4)
c BP1/5 (Through Beam)
1108    6 -2.7   203 -502 501 -5
1109    8 -0.001225  203 -501 -5
c BP2 (Tangential)
1110    6 -2.7   -504 503 -505 -5
1111    8 -0.001225  -503 -505 -5
c BP3 (Radial Penetrating)
1112    6 -2.7  203 -507 506 -4 -5
1113    8 -0.001225 203 -506 -4 -5
c BP4 (Radial)
1114    6 -2.7   203 -509 508 -3 -5
1115    8 -0.001225  203 -508 -3 -5
c ---------------------------------------------------------------------------
c  SOLID AL: fill=1 ** WATER VOID: fill=2 ** GRAPHITE ROD: fill=3
c  FUEL: fill=4 ** CENTRAL THIMBLE: fill=5 ** TRANSIENT ROD: fill=6 **
c  REGULATING ROD: fill=7 ** SHIM 1 fill=8 ** SHIM 2: fill=9 **
c  PNT: fill=10 ** SOURCE: fill=11
c ---------------------------------------------------------------------------
1201     0  -1 406 -202 -204  fill=20 $ lattice space
c       FACET:  -(L) +(R) -(Lu) +(Rl) -(Ru) +(Ll)  +(l) -(u)
1202     0  -101 102 -103 104 -105 106 -1 406 u=20 lat=2 $ lattice 19.05<z<70
            fill=-7:7 -7:7 0:0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  $ROW 1
       1 1 1 1 1 1 1 1 4 4 4 4 4 1 1  $ROW 2
        1 1 1 1 1 1 4 4 4 4 4 4 4 11 1  $ROW 3
         1 1 1 1 1 4 4 4 4 4 4 4 4 4 1  $ROW 4
          1 1 1 1 4 4 4 4 9 4 4 4 4 10 1  $ROW 5
           1 1 1 4 4 4 4 4 4 4 4 4 4 4 1  $ROW 6
            1 1 4 4 4 4 4 4 4 4 4 4 4 4 1  $ROW 7
             1 1 4 4 4 7 4 5 4 6 4 4 4 1 1  $ROW 8
              1 4 4 4 4 4 4 4 4 4 4 4 4 1 1  $ROW 9
```

```
               1 4 12 13 4 4 4 4 4 4 4 4 1 1 1  $ROW 10
                1 4 2 4 4 8 4 4 4 4 4 1 1 1 1  $ROW 11
                 1 4 4 4 4 4 4 4 4 4 1 1 1 1 1  $ROW 12
                  1 4 4 4 4 4 4 4 4 1 1 1 1 1 1  $ROW 13
                   1 1 4 4 4 4 4 1 1 1 1 1 1 1 1  $ROW 14
                    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  $ROW 15
1203     0  -406 413 -202 -204  fill=21 $ lattice space
1204     0  -101 102 -103 104 -105 106 -406 413 u=21 lat=2 $ lattice -19.05<z<19.05
            fill=-7:7 -7:7 0:0
                  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  $ROW 1
         1 1 1 1 1 1 1 1  726  727  728 729 730 1 1  $ROW 2
        1 1 1 1 1 1 724 621 622 623 624 625 626 11 1  $ROW 3
         1 1 1 1 1 723 620 517 518 519 520 521 627 733 1  $ROW 4
          1 1 1 1 722 619 516 413   9 415 416 522 628 10 1  $ROW 5
           1 1 1 721 618 515 412 309 310 311 417 523 629 735 1  $ROW 6
            1 1 720 617 514 411 308 205 206 312 418 524 630 736 1  $ROW 7
             1 1 616 513 410   7 204 5 201   6 401 501 601 1 1  $ROW 8
              1 718 615 512 409 306 203 202 302 402 502 602 702 1 1  $ROW 9
               1 717 12 13 408 305 304 303 403 503 603 703 1 1 1  $ROW 10
                1 716 2 510 407   8 405 404 504 604 704 1 1 1 1  $ROW 11
                 1 715 612 509 508 507 506 505 605 705 1 1 1 1 1  $ROW 12
                  1 714 611 610 609 608 607 606 706 1 1 1 1 1 1  $ROW 13
                          1 1 712 711 710 709 708 1 1 1 1 1 1 1 1  $ROW 14
                    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  $ROW 15
1205     0  -413 2 -202 -204  fill=22 $ lattice space
1206     0  -101 102 -103 104 -105 106 -413 2 u=22 lat=2 $ lattice -70<z<-19.05
            fill=-7:7 -7:7 0:0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  $ROW 1
       1 1 1 1 1 1 1 1 4 4 4 4 4 1 1  $ROW 2
        1 1 1 1 1 1 4 4 4 4 4 4 4 11 1  $ROW 3
         1 1 1 1 1 4 4 4 4 4 4 4 4 4 1  $ROW 4
          1 1 1 1 4 4 4 4 9 4 4 4 4 10 1  $ROW 5
           1 1 1 4 4 4 4 4 4 4 4 4 4 4 1  $ROW 6
            1 1 4 4 4 4 4 4 4 4 4 4 4 4 1  $ROW 7
             1 1 4 4 4 7 4 5 4 6 4 4 4 1 1  $ROW 8
              1 4 4 4 4 4 4 4 4 4 4 4 4 1 1  $ROW 9
               1 4 12 13 4 4 4 4 4 4 4 4 1 1 1  $ROW 10
                1 4 2 4 4 8 4 4 4 4 4 1 1 1 1  $ROW 11
                 1 4 4 4 4 4 4 4 4 4 1 1 1 1 1  $ROW 12
                  1 4 4 4 4 4 4 4 4 1 1 1 1 1 1  $ROW 13
                   1 1 4 4 4 4 4 1 1 1 1 1 1 1 1  $ROW 14
                    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  $ROW 15
c ---------------------------------------------------------------------------
c UNIVERSE 1: Solid Grid Plate and Water
10001  2  -1.0      402 u=1 $ H2O > UPPER GRID PLATE
10002  6  -2.7 -402 403 u=1 $ UPPER GRID PLATE AL
10003  2  -1.0 -403 422 u=1 $ H2O BETWEEN GRID PLATES
10004  6  -2.7 -422 423 u=1 $ LOWER GRID PLATE AL
10005  2  -1.0     -423 u=1 $ H2O < LOWER GRID PLATE
c UNIVERSE 2: Water Holes
```

```
20001  2 -1.0                           402 u=2  $ H2O > UPPER GRID PLATE
20002  8 -0.001225         -321 423 425 -402 u=2  $ Air in tube
20003  6 -2.7              321 -322 423 -402 u=2  $ Inner aluminum tube
20004  9950 -8.65          322 -323 423 -402 u=2  $ Cadmium tube
20005  6 -2.7              323 -324 423 -402 u=2  $ Cd-B Al tube
20006  9951 -1.50          324 -325 423 -402 u=2  $ Boron tube
20007  6 -2.7              325 -326 423 -402 u=2  $ B-U Al tube
20008  9949 -5.00          326 -327 423 -402 u=2  $ Uranium tube
20009  6 -2.7              327 -328 423 -402 u=2  $ Outer aluminum tube
20010  2 -1.0                   328 423 -402 u=2  $ Water outside of aluminum
20011  8 -0.001225                      -425 u=2  $ Air in tally sample
20012  2 -1.0                           -423 u=2  $ H2O < LOWER GRID PLATE
c UNIVERSE 12: Water Holes
120001  2 -1.0                          402 u=12  $ H2O > UPPER GRID PLATE
120002  8 -0.001225       -331 423 426 -402 u=12  $ Air in tube
120003  6 -2.7            331 -332 423 -402 u=12  $ Inner aluminum tube
120004  9950 -8.65        332 -333 423 -402 u=12  $ Cadmium tube
120005  6 -2.7            333 -334 423 -402 u=12  $ Cd-B Al tube
120006  9951 -1.50        334 -335 423 -402 u=12  $ Boron tube
120007  6 -2.7            335 -336 423 -402 u=12  $ B-U Al tube
120008  9949 -5.00        336 -337 423 -402 u=12  $ Uranium tube
120009  6 -2.7            337 -338 423 -402 u=12  $ Outer aluminum tube
120010  2 -1.0                 338 423 -402 u=12  $ Water outside of aluminum
120011  8 -0.001225                    -426 u=12  $ Air in tally sample
120012  2 -1.0                         -423 u=12  $ H2O < LOWER GRID PLATE
c UNIVERSE 13: Water Holes
130001  2 -1.0                          402 u=13  $ H2O > UPPER GRID PLATE
130002  8 -0.001225       -341 423 427 -402 u=13  $ Air in tube
130003  6 -2.7            341 -342 423 -402 u=13  $ Inner aluminum tube
130004  9950 -8.65        342 -343 423 -402 u=13  $ Cadmium tube
130005  6 -2.7            343 -344 423 -402 u=13  $ Cd-B Al tube
130006  9951 -1.50        344 -345 423 -402 u=13  $ Boron tube
130007  6 -2.7            345 -346 423 -402 u=13  $ B-U Al tubetube
130008  9949 -5.00        346 -347 423 -402 u=13  $ Uranium tube
130009  6 -2.7            347 -348 423 -402 u=13  $ Outer aluminum tube
130010  2 -1.0                 348 423 -402 u=13  $ Water outside of aluminum
130011  8 -0.001225                    -427 u=13  $ Air in tally sample
130012  2 -1.0                         -423 u=13  $ H2O < LOWER GRID PLATE
c UNIVERSE 3: Graphite Element
30001  2  -1.0              (317:401:424) 402 u=3 $ H2O > UPPER GRID PLATE
30002  2  -1.0    (317:401:424) -319 -402 403 u=3 $ H2O UPPER GRID
30003  6  -2.7                   319 -402 403 u=3 $ UPPER GRID PLATE AL
30004 22  -1.0         (317:401:424) -403 422 u=3 $ H2O INSIDE GRID PLATE
30005 55  -1.6                  -316 -404 420 u=3 $ GRAPHITE
30006  6  -2.7                   309 -422 423 u=3 $ LOWER GRID PLATE AL
30007  2  -1.0        (317:424) -309 -422 423 u=3 $ LOWER GRID PLATE H2O
30008  2  -1.0             (317:401:424) -423 u=3 $ H2O < LOWER GRID PLATE
30009  6  -2.7 -317 -401 -424#(-316 -404 420) u=3 $ CLADDING
c UNIVERSE 4: Fuel Element
40001  2  -1.0           (317:401:424) 402 u=4 $ H2O > UPPER GRID PLATE
```

```
40002 22  -1.0 (317:401:424) -319 -402 403 u=4 $ H2O AROUND UPPER GRID PLATE
40003  6  -2.7                319 -402 403 u=4 $ UPPER GRID PLATE AL
40004 22  -1.0          (317:401) -403 406 u=4 $ H2O ABOVE FUEL
40005  8  -0.001225          -316 -404 405 u=4 $ AIR BELOW PLUG
40006  8  -0.001225      315 -316 -405 406 u=4 $ AIR ABOVE FUEL
40007 55  -1.6               -315 -405 406 u=4 $ UPPER GRAPHITE
40008  4   0.0858        316 -317 -404 406 u=4 $ UPPER CLADDING
40009  4   0.0858            -317 -401 404 u=4 $ UPPER FLUTES
40010  8  -0.001225      315 -316 -413 420 u=4 $ AIR BELOW FUEL
40011  4   0.0858        316 -317 -413 420 u=4 $ LOWER CLADDING
40012 22  -1.0          (317:424) -413 422 u=4 $ H2O BELOW FUEL
40013  6  -2.7                309 -422 423 u=4 $ LOWER GRID PLATE AL
40014  2  -1.0     (317:424) -309 -422 423 u=4 $ LOWER GRID PLATE H2O
40015  2  -1.0          (317:401:424) -423 u=4 $ H2O < LOWER GRID PLATE
40016  4   0.0858           -317 -424 -420 u=4 $ LOWER FLUTES
40017 10 -10.3               -315 -413 414 u=4 $ MOLY DISK
40018 55  -1.6               -315 -414 420 u=4 $ LOWER GRAPHITE
c Portion of Fuel Element in Axial Fuel Meat Region (Universe 21 above)
40019 22 -1.0           317 -406 413 u=4 $ H2O
40020  4  0.0858   316 -317 -406 413 u=4 $ CLADDING
40021  3  0.0408       -301 -406 413 u=4 $ ZIRC FILL ROD
40022  1 -5.85     -316 301 -406 407 u=4 $ FUEL SLUG 1
40023  1 -5.85     -316 301 -407 411 u=4 $ FUEL SLUG 2
40024  1 -5.85     -316 301 -411 413 u=4 $ FUEL SLUG 3
c UNIVERSE 5: Central Thimble
50001  2 -1.0      318 402 u=5 $ H2O > UPPER GRID PLATE
50002  6 -2.7 318 -402 403 u=5 $ UPPER GRID PLATE AL
50003 22 -1.0 318 -403 422 u=5 $ H2O BETWEEN GRID PLATE
50004  6 -2.7 318 -422 423 u=5 $ LOWER GRID PLATE AL
50005 22 -1.0       -313 2 u=5 $ H2O in thimble
50006  6 -2.7   313 -318 2 u=5 $ Thimble (aluminum)
50007  2 -1.0   318 -423 2 u=5 $ H2O < LOWER GRID PLATE
c UNIVERSE 6, Transient Rod
60001  2 -1.0           (309:601:-607) 402 u=6 $ H2O > UPPER GRID
60002 22 -1.0 (309:601:-607) -319 -402 403 u=6 $ H2O IN UPPER GRID
60003  6 -2.7                 319 -402 403 u=6 $ UPPER GRID PLATE AL
60004 22 -1.0      (309:601:-607) -403 422 u=6 $ H2O BETWEEN GRIDS
60005 22 -1.0 (309:601:-607) -319 -422 423 u=6 $ H2O IN LOWER GRID
60006  6 -2.7                 319 -422 423 u=6 $ LOWER GRID PLATE AL
60007  2 -1.0          (309:601:-607) -423 u=6 $ H2O < LOWER GRID
60008  6 -2.7      308 -309 -601 607 u=6 $ CLADDING
60009  6 -2.7          -308 -601 602 u=6 $ element clad
60010  6 -2.7          -308 -602 603 u=6 $ spacer plug
60011  9 -2.48         -307 -603 604 u=6 $ absorber
60012  8 -0.001225 307 -308 -603 604 u=6 $ air around absorber
60013  6 -2.7          -308 -604 605 u=6 $ spacer plug
60014  8 -0.001225     -308 -605 606 u=6 $ air follower
60015  6 -2.7          -308 -606 607 u=6 $ end plug
c UNIVERSE 7: Fuel Follower Control Rod, Regulating Rod
70001  2 -1.0            (314:701:-714) 402 u=7 $ H2O > UPPER GRID
```

```
70002 22 -1.0  (314:701:-714) -319 -402 403 u=7 $ H2O IN UPPER GRID
70003  6 -2.7                  319 -402 403 u=7 $ UPPER GRID PLATE AL
70004 22 -1.0       (314:701:-714) -403 422 u=7 $ H2O BETWEEN GRIDS
70005 22 -1.0  (314:701:-714) -319 -422 423 u=7 $ H2O IN LOWER GRID
70006  6 -2.7                  319 -422 423 u=7 $ LOWER GRID PLATE AL
70007  2 -1.0           (314:701:-714) -423 u=7 $ H2O < LOWER GRID
70008  4  0.0858       -312 -701 702 u=7 $ end plug
70009  8 -0.001225     -312 -702 703 u=7 $ top space
70010  4  0.0858       -312 -703 704 u=7 $ spacer plug
70011  8 -0.001225     -312 -704 705 u=7 $ void gap
70012  9 -2.48         -311 -705 706 u=7 $ absorber
70023  8 -0.001225 311 -312 -705 706 u=7 $ air around absorber
70013  4  0.0858       -312 -706 707 u=7 $ spacer plug
70014  8 -0.001225     -312 -707 708 u=7 $ void gap
c  **   fuel   **
70015  9948 -6.0124 -312 301 -708 709 vol=106.41 u=7 $ Fuel Slug 1
70016  9948 -6.0124 -312 301 -709 710 vol=106.41 u=7 $ Fuel Slug 2
70017  9948 -6.0124 -312 301 -710 711 vol=106.41 u=7 $ Fuel Slug 3
c **  end fuel  **
70018  3  0.0408     -301 -708 711 u=7 $ Zr rod
70019  4  0.0858     -312 -711 712 u=7 $ spacer plug
70020  8 -0.001225   -312 -712 713 u=7 $ bottom void
70021  4  0.0858     -312 -713 714 u=7 $ end plug
70022  4  0.0858 312 -314 -701 714 u=7 $ element clad
c UNIVERSE 8: Fuel Follower Control Rod, Shim 1 Rod
80001  2 -1.0            (314:801:-814) 402 u=8 $ H2O > UPPER GRID
80002 22 -1.0  (314:801:-814) -319 -402 403 u=8 $ H2O IN UPPER GRID
80003  6 -2.7                  319 -402 403 u=8 $ UPPER GRID PLATE AL
80004 22 -1.0       (314:801:-814) -403 422 u=8 $ H2O BETWEEN GRIDS
80005 22 -1.0  (314:801:-814) -319 -422 423 u=8 $ H2O IN LOWER GRID
80006  6 -2.7                  319 -422 423 u=8 $ LOWER GRID PLATE AL
80007  2 -1.0           (314:801:-814) -423 u=8 $ H2O < LOWER GRID
80008  4  0.0858       -312 -801 802 u=8 $ end plug
80009  8 -0.001225     -312 -802 803 u=8 $ top space
80010  4  0.0858       -312 -803 804 u=8 $ spacer plug
80011  8 -0.001225     -312 -804 805 u=8 $ void gap
80012  9   -2.48       -311 -805 806 u=8 $ absorber
80023  8 -0.001225 311 -312 -805 806 u=8 $ air around absorber
80013  4  0.0858       -312 -806 807 u=8 $ spacer plug
80014  8 -0.001225     -312 -807 808 u=8 $ void gap
c  **   fuel   **
80015  9946 -6.0124 -312 301 -808 809 vol=106.41 u=8 $ Fuel Slug 1
80016  9946 -6.0124 -312 301 -809 810 vol=106.41 u=8 $ Fuel Slug 2
80017  9946 -6.0124 -312 301 -810 811 vol=106.41 u=8 $ Fuel Slug 3
c **  end fuel  **
80018  3  0.0408     -301 -808 811 u=8 $ Zr rod
80019  4  0.0858     -312 -811 812 u=8 $ spacer plug
80020  8 -0.001225   -312 -812 813 u=8 $ bottom void
80021  4  0.0858     -312 -813 814 u=8 $ end plug
80022  4  0.0858 312 -314 -801 814 u=8 $ element cladding
```

```
c UNIVERSE 9: Fuel Follower Control Rod, Shim 2 Rod
90001  2 -1.0            (314:901:-914) 402 u=9 $ H2O > UPPER GRID
90002 22 -1.0  (314:901:-914) -319 -402 403 u=9 $ H2O IN UPPER GRID
90003  6 -2.7                  319 -402 403 u=9 $ UPPER GRID PLATE AL
90004 22 -1.0       (314:901:-914) -403 422 u=9 $ H2O BETWEEN GRIDS
90005 22 -1.0  (314:901:-914) -319 -422 423 u=9 $ H2O IN LOWER GRID
90006  6 -2.7                  319 -422 423 u=9 $ LOWER GRID PLATE AL
90007  2 -1.0           (314:901:-914) -423 u=9 $ H2O < LOWER GRID
90008  4  0.0858       -312 -901 902 u=9 $ end plug
90009  8 -0.001225     -312 -902 903 u=9 $ top space
90010  4  0.0858       -312 -903 904 u=9 $ spacer plug
90011  8 -0.001225     -312 -904 905 u=9 $ void gap
90012  9   -2.48       -311 -905 906 u=9 $ absorber
90023  8 -0.001225 311 -312 -905 906 u=9 $ air around absorber
90013  4  0.0858       -312 -906 907 u=9 $ spacer plug
90014  8 -0.001225     -312 -907 908 u=9 $ void gap
c  **  fuel   **
90015  9947 -6.0124 -312 301 -908 909 vol=106.41 u=9 $ Fuel Slug 1
90016  9947 -6.0124 -312 301 -909 910 vol=106.41 u=9 $ Fuel Slug 2
90017  9947 -6.0124 -312 301 -910 911 vol=106.41 u=9 $ Fuel Slug 3
c ** end fuel  **
90018  3  0.0408     -301 -908 911 u=9 $ Zr rod
90019  4  0.0858     -312 -911 912 u=9 $ spacer plug
90020  8 -0.001225   -312 -912 913 u=9 $ bottom void
90021  4  0.0858     -312 -913 914 u=9 $ end plug
90022  4  0.0858 312 -314 -901 914 u=9 $ element clad
c  UNIVERSE 10: Pneumatic Tube
100001  2 -1.0                   402 u=10 $ H2O > UPPER GRID PLATE
100002  6 -2.7          319 -402 403 u=10 $ UPPER GRID PLATE AL
100003 22 -1.0          319 -403 422 u=10 $ H2O BETWEEN GRID PLATE
100004  6 -2.7          319 -422 423 u=10 $ LOWER GRID PLATE AL
100005  2 -1.0                  -423 u=10 $ H2O < LOWER GRID PLATE
c Use 100006-100014 if modeling unlined rabbit
100006  6 -2.7  302 -303 -402 412 u=10 $ Pneumatic Tube top (aluminum)
100007  2 -1.0  303 -319 -402 412 u=10 $ Pneumatic Tube top (water)
100008  6 -2.7      -303 -412 417 u=10 $ Pneumatic Tube middle (aluminum)
100009  2 -1.0  303 -319 -412 417 u=10 $ Pneumatic Tube middle (water)
100010  6 -2.7      -310 -417 419 u=10 $ Pneumatic Tube connecting tube (aluminum)
100011  2 -1.0  310 -319 -417 419 u=10 $ Pneumatic Tube connecting tube (water)
100012  6 -2.7      -303 -419 423 u=10 $ Pneumatic Tube bottom (aluminum)
100013  2 -1.0  303 -319 -419 423 u=10 $ Pneumatic Tube bottom (water)
100014  8 -0.001225 -302 -402 412 u=10 $ Air in Tube
c Use 100006-100023 if modeling cadmium rabbit
c 100006  6 -2.7      302 -303 -402 412 u=10 $ Pneumatic Tube top (aluminum)
c 100007  8 -0.001225     -302 -402 412 u=10 $ Air in Tube
c 100008  20 -8.65    303 -304 -402 412 u=10 $ Cadmium double wrap
c 100009  8 -0.001225 304 -306 -402 412 u=10 $ Air between cadmium and outer tube
c 100010  6 -2.7      306 -310 -402 412 u=10 $ Pneumatic Tube (aluminum)
c 100011 22 -1.0      310 -319 -402 412 u=10 $ Pneumatic Tube top (water)
c 100012  6 -2.7          -310 -412 415 u=10 $ Pneumatic Tube middle (aluminum)
```

```
c 100013 22 -1.0      310 -319 -412 415 u=10 $ Pneumatic Tube middle (water)
c 100014 20 -8.65         -302 -415 416 u=10 $ Pneumatic Tube Cd discs (cadmium)
c 100015  6 -2.7      302 -303 -415 416 u=10 $ Pneumatic Tube Cd discs (aluminum)
c 100016 22 -1.0      303 -319 -415 416 u=10 $ Pneumatic Tube Cd discs (water)
c 100017  6 -2.7          -316 -416 417 u=10 $ Pneumatic Tube middle (aluminum)
c 100018 22 -1.0      316 -319 -416 417 u=10 $ Pneumatic Tube middle (water)
c 100019  6 -2.7          -310 -417 419 u=10 $ Pneumatic Tube connecting tube
(aluminum)
c 100020 22 -1.0      310 -319 -417 419 u=10 $ Pneumatic Tube connecting tube
(water)
c 100021  6 -2.7          -316 -419 423 u=10 $ Pneumatic Tube bottom (aluminum)
c 100022 22 -1.0      316 -319 -419 423 u=10 $ Pneumatic Tube bottom (water)
c 100023  8 -0.001225     -302 -402 412 u=10 $ Air in Tube
c  UNIVERSE 11: Source
110001  2 -1.0                402 u=11 $ H2O > UPPER GRID PLATE
110002  6 -2.7       319 -402 403 u=11 $ UPPER GRID PLATE AL
110003 22 -1.0       319 -403 422 u=11 $ H2O BETWEEN GRID PLATE
110004 22 -1.0  316 -319 -402 422 u=11 $ Water around source
110005  6 -2.7       309 -422 423 u=11 $ LOWER GRID PLATE AL
110006  2 -1.0      -309 -422 423 u=11 $ LOWER GRID PLATE AL
110007  2 -1.0               -423 u=11 $ H2O < LOWER GRID PLATE
110008  6 -2.7      -316 -402 408 u=11 $ Source Holder top (aluminum)
110009  6 -2.7  305 -316 -408 410 u=11 $ Source Holder middle (aluminum)
110010  8 -0.001225 -305 -408 410 u=11 $ Air in Tube (source)
110011  6 -2.7      -316 -410 421 u=11 $ Source Holder (bottom)
110012 22 -1.0      -316 -421 422 u=11 $ Water under source
c ************************* END UNIVERSES **************************
c ----------------Lazy Susan----------------
18001  6 -2.7      -403 409 1301 -1341 $ LS rack cladding
18002  6 -2.7      -403 409 1302 -1342
18003  6 -2.7      -403 409 1303 -1343
18004  6 -2.7      -403 409 1304 -1344
18005  6 -2.7      -403 409 1305 -1345
18006  6 -2.7      -403 409 1306 -1346
18007  6 -2.7      -403 409 1307 -1347
18008  6 -2.7      -403 409 1308 -1348
18009  6 -2.7      -403 409 1309 -1349
18010  6 -2.7      -403 409 1310 -1350
18011  6 -2.7      -403 409 1311 -1351
18012  6 -2.7      -403 409 1312 -1352
18013  6 -2.7      -403 409 1313 -1353
18014  6 -2.7      -403 409 1314 -1354
18015  6 -2.7      -403 409 1315 -1355
18016  6 -2.7      -403 409 1316 -1356
18017  6 -2.7      -403 409 1317 -1357
18018  6 -2.7      -403 409 1318 -1358
18019  6 -2.7      -403 409 1319 -1359
18020  6 -2.7      -403 409 1320 -1360
18021  6 -2.7      -403 409 1321 -1361
18022  6 -2.7      -403 409 1322 -1362
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18023  6 -2.7      -403 409 1323 -1363
18024  6 -2.7      -403 409 1324 -1364
18025  6 -2.7      -403 409 1325 -1365
18026  6 -2.7      -403 409 1326 -1366
18027  6 -2.7      -403 409 1327 -1367
18028  6 -2.7      -403 409 1328 -1368
18029  6 -2.7      -403 409 1329 -1369
18030  6 -2.7      -403 409 1330 -1370
18031  6 -2.7      -403 409 1331 -1371
18032  6 -2.7      -403 409 1332 -1372
18033  6 -2.7      -403 409 1333 -1373
18034  6 -2.7      -403 409 1334 -1374
18035  6 -2.7      -403 409 1335 -1375
18036  6 -2.7      -403 409 1336 -1376
18037  6 -2.7      -403 409 1337 -1377
18038  6 -2.7      -403 409 1338 -1378
18039  6 -2.7      -403 409 1339 -1379
18040  6 -2.7      -403 409 1340 -1380
18041  8 -0.001225 -403 1381 -1301 $ Air from 10 cm to top of LS
18042  8 -0.001225 -403 1381 -1302
18043  8 -0.001225 -403 1381 -1303
18044  8 -0.001225 -403 1381 -1304
18045  8 -0.001225 -403 1381 -1305
18046  8 -0.001225 -403 1381 -1306
18047  8 -0.001225 -403 1381 -1307
18048  8 -0.001225 -403 1381 -1308
18049  8 -0.001225 -403 1381 -1309
18050  8 -0.001225 -403 1381 -1310
18051  8 -0.001225 -403 1381 -1311
18052  8 -0.001225 -403 1381 -1312
18053  8 -0.001225 -403 1381 -1313
18054  8 -0.001225 -403 1381 -1314
18055  8 -0.001225 -403 1381 -1315
18056  8 -0.001225 -403 1381 -1316
18057  8 -0.001225 -403 1381 -1317
18058  8 -0.001225 -403 1381 -1318
18059  8 -0.001225 -403 1381 -1319
18060  8 -0.001225 -403 1381 -1320
18061  8 -0.001225 -403 1381 -1321
18062  8 -0.001225 -403 1381 -1322
18063  8 -0.001225 -403 1381 -1323
18064  8 -0.001225 -403 1381 -1324
18065  8 -0.001225 -403 1381 -1325
18066  8 -0.001225 -403 1381 -1326
18067  8 -0.001225 -403 1381 -1327
18068  8 -0.001225 -403 1381 -1328
18069  8 -0.001225 -403 1381 -1329
18070  8 -0.001225 -403 1381 -1330
18071  8 -0.001225 -403 1381 -1331
18072  8 -0.001225 -403 1381 -1332
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18073  8 -0.001225 -403 1381 -1333
18074  8 -0.001225 -403 1381 -1334
18075  8 -0.001225 -403 1381 -1335
18076  8 -0.001225 -403 1381 -1336
18077  8 -0.001225 -403 1381 -1337
18078  8 -0.001225 -403 1381 -1338
18079  8 -0.001225 -403 1381 -1339
18080  8 -0.001225 -403 1381 -1340
c Bottom of each lazy susan sample
18100  8 -0.001225 409 -1390 -1340
18101  8 -0.001225 409 -1390 -1339
18102  8 -0.001225 409 -1390 -1338
18103  8 -0.001225 409 -1390 -1337
18104  8 -0.001225 409 -1390 -1336
18105  8 -0.001225 409 -1390 -1335
18106  8 -0.001225 409 -1390 -1334
18107  8 -0.001225 409 -1390 -1333
18108  8 -0.001225 409 -1390 -1332
18109  8 -0.001225 409 -1390 -1331
18110  8 -0.001225 409 -1390 -1330
18111  8 -0.001225 409 -1390 -1329
18112  8 -0.001225 409 -1390 -1328
18113  8 -0.001225 409 -1390 -1327
18114  8 -0.001225 409 -1390 -1326
18115  8 -0.001225 409 -1390 -1325
18116  8 -0.001225 409 -1390 -1324
18117  8 -0.001225 409 -1390 -1323
18118  8 -0.001225 409 -1390 -1322
18119  8 -0.001225 409 -1390 -1321
18120  8 -0.001225 409 -1390 -1320
18121  8 -0.001225 409 -1390 -1319
18122  8 -0.001225 409 -1390 -1318
18123  8 -0.001225 409 -1390 -1317
18124  8 -0.001225 409 -1390 -1316
18125  8 -0.001225 409 -1390 -1315
18126  8 -0.001225 409 -1390 -1314
18127  8 -0.001225 409 -1390 -1313
18128  8 -0.001225 409 -1390 -1312
18129  8 -0.001225 409 -1390 -1311
18130  8 -0.001225 409 -1390 -1310
18131  8 -0.001225 409 -1390 -1309
18132  8 -0.001225 409 -1390 -1308
18133  8 -0.001225 409 -1390 -1307
18134  8 -0.001225 409 -1390 -1306
18135  8 -0.001225 409 -1390 -1305
18136  8 -0.001225 409 -1390 -1304
18137  8 -0.001225 409 -1390 -1303
18138  8 -0.001225 409 -1390 -1302
18139  8 -0.001225 409 -1390 -1301
c 1 cm off bottom of lazy susan sample
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18140  8 -0.001225 1390 -1389 -1340
18141  8 -0.001225 1390 -1389 -1339
18142  8 -0.001225 1390 -1389 -1338
18143  8 -0.001225 1390 -1389 -1337
18144  8 -0.001225 1390 -1389 -1336
18145  8 -0.001225 1390 -1389 -1335
18146  8 -0.001225 1390 -1389 -1334
18147  8 -0.001225 1390 -1389 -1333
18148  8 -0.001225 1390 -1389 -1332
18149  8 -0.001225 1390 -1389 -1331
18150  8 -0.001225 1390 -1389 -1330
18151  8 -0.001225 1390 -1389 -1329
18152  8 -0.001225 1390 -1389 -1328
18153  8 -0.001225 1390 -1389 -1327
18154  8 -0.001225 1390 -1389 -1326
18155  8 -0.001225 1390 -1389 -1325
18156  8 -0.001225 1390 -1389 -1324
18157  8 -0.001225 1390 -1389 -1323
18158  8 -0.001225 1390 -1389 -1322
18159  8 -0.001225 1390 -1389 -1321
18160  8 -0.001225 1390 -1389 -1320
18161  8 -0.001225 1390 -1389 -1319
18162  8 -0.001225 1390 -1389 -1318
18163  8 -0.001225 1390 -1389 -1317
18164  8 -0.001225 1390 -1389 -1316
18165  8 -0.001225 1390 -1389 -1315
18166  8 -0.001225 1390 -1389 -1314
18167  8 -0.001225 1390 -1389 -1313
18168  8 -0.001225 1390 -1389 -1312
18169  8 -0.001225 1390 -1389 -1311
18170  8 -0.001225 1390 -1389 -1310
18171  8 -0.001225 1390 -1389 -1309
18172  8 -0.001225 1390 -1389 -1308
18173  8 -0.001225 1390 -1389 -1307
18174  8 -0.001225 1390 -1389 -1306
18175  8 -0.001225 1390 -1389 -1305
18176  8 -0.001225 1390 -1389 -1304
18177  8 -0.001225 1390 -1389 -1303
18178  8 -0.001225 1390 -1389 -1302
18179  8 -0.001225 1390 -1389 -1301
c 2 cm off bottom of lazy susan sample
18180  8 -0.001225 1389 -1388 -1340
18181  8 -0.001225 1389 -1388 -1339
18182  8 -0.001225 1389 -1388 -1338
18183  8 -0.001225 1389 -1388 -1337
18184  8 -0.001225 1389 -1388 -1336
18185  8 -0.001225 1389 -1388 -1335
18186  8 -0.001225 1389 -1388 -1334
18187  8 -0.001225 1389 -1388 -1333
18188  8 -0.001225 1389 -1388 -1332
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18189  8 -0.001225 1389 -1388 -1331
18190  8 -0.001225 1389 -1388 -1330
18191  8 -0.001225 1389 -1388 -1329
18192  8 -0.001225 1389 -1388 -1328
18193  8 -0.001225 1389 -1388 -1327
18194  8 -0.001225 1389 -1388 -1326
18195  8 -0.001225 1389 -1388 -1325
18196  8 -0.001225 1389 -1388 -1324
18197  8 -0.001225 1389 -1388 -1323
18198  8 -0.001225 1389 -1388 -1322
18199  8 -0.001225 1389 -1388 -1321
18200  8 -0.001225 1389 -1388 -1320
18201  8 -0.001225 1389 -1388 -1319
18202  8 -0.001225 1389 -1388 -1318
18203  8 -0.001225 1389 -1388 -1317
18204  8 -0.001225 1389 -1388 -1316
18205  8 -0.001225 1389 -1388 -1315
18206  8 -0.001225 1389 -1388 -1314
18207  8 -0.001225 1389 -1388 -1313
18208  8 -0.001225 1389 -1388 -1312
18209  8 -0.001225 1389 -1388 -1311
18210  8 -0.001225 1389 -1388 -1310
18211  8 -0.001225 1389 -1388 -1309
18212  8 -0.001225 1389 -1388 -1308
18213  8 -0.001225 1389 -1388 -1307
18214  8 -0.001225 1389 -1388 -1306
18215  8 -0.001225 1389 -1388 -1305
18216  8 -0.001225 1389 -1388 -1304
18217  8 -0.001225 1389 -1388 -1303
18218  8 -0.001225 1389 -1388 -1302
18219  8 -0.001225 1389 -1388 -1301
c 3 cm off bottom of lazy susan sample
18220  8 -0.001225 1388 -1387 -1340
18221  8 -0.001225 1388 -1387 -1339
18222  8 -0.001225 1388 -1387 -1338
18223  8 -0.001225 1388 -1387 -1337
18224  8 -0.001225 1388 -1387 -1336
18225  8 -0.001225 1388 -1387 -1335
18226  8 -0.001225 1388 -1387 -1334
18227  8 -0.001225 1388 -1387 -1333
18228  8 -0.001225 1388 -1387 -1332
18229  8 -0.001225 1388 -1387 -1331
18230  8 -0.001225 1388 -1387 -1330
18231  8 -0.001225 1388 -1387 -1329
18232  8 -0.001225 1388 -1387 -1328
18233  8 -0.001225 1388 -1387 -1327
18234  8 -0.001225 1388 -1387 -1326
18235  8 -0.001225 1388 -1387 -1325
18236  8 -0.001225 1388 -1387 -1324
18237  8 -0.001225 1388 -1387 -1323
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18238  8 -0.001225 1388 -1387 -1322
18239  8 -0.001225 1388 -1387 -1321
18240  8 -0.001225 1388 -1387 -1320
18241  8 -0.001225 1388 -1387 -1319
18242  8 -0.001225 1388 -1387 -1318
18243  8 -0.001225 1388 -1387 -1317
18244  8 -0.001225 1388 -1387 -1316
18245  8 -0.001225 1388 -1387 -1315
18246  8 -0.001225 1388 -1387 -1314
18247  8 -0.001225 1388 -1387 -1313
18248  8 -0.001225 1388 -1387 -1312
18249  8 -0.001225 1388 -1387 -1311
18250  8 -0.001225 1388 -1387 -1310
18251  8 -0.001225 1388 -1387 -1309
18252  8 -0.001225 1388 -1387 -1308
18253  8 -0.001225 1388 -1387 -1307
18254  8 -0.001225 1388 -1387 -1306
18255  8 -0.001225 1388 -1387 -1305
18256  8 -0.001225 1388 -1387 -1304
18257  8 -0.001225 1388 -1387 -1303
18258  8 -0.001225 1388 -1387 -1302
18259  8 -0.001225 1388 -1387 -1301
c 4 cm off bottom of lazy susan sample
18260  8 -0.001225 1387 -1386 -1340
18261  8 -0.001225 1387 -1386 -1339
18262  8 -0.001225 1387 -1386 -1338
18263  8 -0.001225 1387 -1386 -1337
18264  8 -0.001225 1387 -1386 -1336
18265  8 -0.001225 1387 -1386 -1335
18266  8 -0.001225 1387 -1386 -1334
18267  8 -0.001225 1387 -1386 -1333
18268  8 -0.001225 1387 -1386 -1332
18269  8 -0.001225 1387 -1386 -1331
18270  8 -0.001225 1387 -1386 -1330
18271  8 -0.001225 1387 -1386 -1329
18272  8 -0.001225 1387 -1386 -1328
18273  8 -0.001225 1387 -1386 -1327
18274  8 -0.001225 1387 -1386 -1326
18275  8 -0.001225 1387 -1386 -1325
18276  8 -0.001225 1387 -1386 -1324
18277  8 -0.001225 1387 -1386 -1323
18278  8 -0.001225 1387 -1386 -1322
18279  8 -0.001225 1387 -1386 -1321
18280  8 -0.001225 1387 -1386 -1320
18281  8 -0.001225 1387 -1386 -1319
18282  8 -0.001225 1387 -1386 -1318
18283  8 -0.001225 1387 -1386 -1317
18284  8 -0.001225 1387 -1386 -1316
18285  8 -0.001225 1387 -1386 -1315
18286  8 -0.001225 1387 -1386 -1314
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18287  8 -0.001225 1387 -1386 -1313
18288  8 -0.001225 1387 -1386 -1312
18289  8 -0.001225 1387 -1386 -1311
18290  8 -0.001225 1387 -1386 -1310
18291  8 -0.001225 1387 -1386 -1309
18292  8 -0.001225 1387 -1386 -1308
18293  8 -0.001225 1387 -1386 -1307
18294  8 -0.001225 1387 -1386 -1306
18295  8 -0.001225 1387 -1386 -1305
18296  8 -0.001225 1387 -1386 -1304
18297  8 -0.001225 1387 -1386 -1303
18298  8 -0.001225 1387 -1386 -1302
18299  8 -0.001225 1387 -1386 -1301
c 5 cm off bottom of lazy susan sample
18300  8 -0.001225 1386 -1385 -1340
18301  8 -0.001225 1386 -1385 -1339
18302  8 -0.001225 1386 -1385 -1338
18303  8 -0.001225 1386 -1385 -1337
18304  8 -0.001225 1386 -1385 -1336
18305  8 -0.001225 1386 -1385 -1335
18306  8 -0.001225 1386 -1385 -1334
18307  8 -0.001225 1386 -1385 -1333
18308  8 -0.001225 1386 -1385 -1332
18309  8 -0.001225 1386 -1385 -1331
18310  8 -0.001225 1386 -1385 -1330
18311  8 -0.001225 1386 -1385 -1329
18312  8 -0.001225 1386 -1385 -1328
18313  8 -0.001225 1386 -1385 -1327
18314  8 -0.001225 1386 -1385 -1326
18315  8 -0.001225 1386 -1385 -1325
18316  8 -0.001225 1386 -1385 -1324
18317  8 -0.001225 1386 -1385 -1323
18318  8 -0.001225 1386 -1385 -1322
18319  8 -0.001225 1386 -1385 -1321
18320  8 -0.001225 1386 -1385 -1320
18321  8 -0.001225 1386 -1385 -1319
18322  8 -0.001225 1386 -1385 -1318
18323  8 -0.001225 1386 -1385 -1317
18324  8 -0.001225 1386 -1385 -1316
18325  8 -0.001225 1386 -1385 -1315
18326  8 -0.001225 1386 -1385 -1314
18327  8 -0.001225 1386 -1385 -1313
18328  8 -0.001225 1386 -1385 -1312
18329  8 -0.001225 1386 -1385 -1311
18330  8 -0.001225 1386 -1385 -1310
18331  8 -0.001225 1386 -1385 -1309
18332  8 -0.001225 1386 -1385 -1308
18333  8 -0.001225 1386 -1385 -1307
18334  8 -0.001225 1386 -1385 -1306
18335  8 -0.001225 1386 -1385 -1305
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18336  8 -0.001225 1386 -1385 -1304
18337  8 -0.001225 1386 -1385 -1303
18338  8 -0.001225 1386 -1385 -1302
18339  8 -0.001225 1386 -1385 -1301
c 6 cm off bottom of lazy susan sample
18340  8 -0.001225 1385 -1384 -1340
18341  8 -0.001225 1385 -1384 -1339
18342  8 -0.001225 1385 -1384 -1338
18343  8 -0.001225 1385 -1384 -1337
18344  8 -0.001225 1385 -1384 -1336
18345  8 -0.001225 1385 -1384 -1335
18346  8 -0.001225 1385 -1384 -1334
18347  8 -0.001225 1385 -1384 -1333
18348  8 -0.001225 1385 -1384 -1332
18349  8 -0.001225 1385 -1384 -1331
18350  8 -0.001225 1385 -1384 -1330
18351  8 -0.001225 1385 -1384 -1329
18352  8 -0.001225 1385 -1384 -1328
18353  8 -0.001225 1385 -1384 -1327
18354  8 -0.001225 1385 -1384 -1326
18355  8 -0.001225 1385 -1384 -1325
18356  8 -0.001225 1385 -1384 -1324
18357  8 -0.001225 1385 -1384 -1323
18358  8 -0.001225 1385 -1384 -1322
18359  8 -0.001225 1385 -1384 -1321
18360  8 -0.001225 1385 -1384 -1320
18361  8 -0.001225 1385 -1384 -1319
18362  8 -0.001225 1385 -1384 -1318
18363  8 -0.001225 1385 -1384 -1317
18364  8 -0.001225 1385 -1384 -1316
18365  8 -0.001225 1385 -1384 -1315
18366  8 -0.001225 1385 -1384 -1314
18367  8 -0.001225 1385 -1384 -1313
18368  8 -0.001225 1385 -1384 -1312
18369  8 -0.001225 1385 -1384 -1311
18370  8 -0.001225 1385 -1384 -1310
18371  8 -0.001225 1385 -1384 -1309
18372  8 -0.001225 1385 -1384 -1308
18373  8 -0.001225 1385 -1384 -1307
18374  8 -0.001225 1385 -1384 -1306
18375  8 -0.001225 1385 -1384 -1305
18376  8 -0.001225 1385 -1384 -1304
18377  8 -0.001225 1385 -1384 -1303
18378  8 -0.001225 1385 -1384 -1302
18379  8 -0.001225 1385 -1384 -1301
c 7 cm off bottom of lazy susan sample
18380  8 -0.001225 1384 -1383 -1340
18381  8 -0.001225 1384 -1383 -1339
18382  8 -0.001225 1384 -1383 -1338
18383  8 -0.001225 1384 -1383 -1337
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18384  8 -0.001225 1384 -1383 -1336
18385  8 -0.001225 1384 -1383 -1335
18386  8 -0.001225 1384 -1383 -1334
18387  8 -0.001225 1384 -1383 -1333
18388  8 -0.001225 1384 -1383 -1332
18389  8 -0.001225 1384 -1383 -1331
18390  8 -0.001225 1384 -1383 -1330
18391  8 -0.001225 1384 -1383 -1329
18392  8 -0.001225 1384 -1383 -1328
18393  8 -0.001225 1384 -1383 -1327
18394  8 -0.001225 1384 -1383 -1326
18395  8 -0.001225 1384 -1383 -1325
18396  8 -0.001225 1384 -1383 -1324
18397  8 -0.001225 1384 -1383 -1323
18398  8 -0.001225 1384 -1383 -1322
18399  8 -0.001225 1384 -1383 -1321
18400  8 -0.001225 1384 -1383 -1320
18401  8 -0.001225 1384 -1383 -1319
18402  8 -0.001225 1384 -1383 -1318
18403  8 -0.001225 1384 -1383 -1317
18404  8 -0.001225 1384 -1383 -1316
18405  8 -0.001225 1384 -1383 -1315
18406  8 -0.001225 1384 -1383 -1314
18407  8 -0.001225 1384 -1383 -1313
18408  8 -0.001225 1384 -1383 -1312
18409  8 -0.001225 1384 -1383 -1311
18410  8 -0.001225 1384 -1383 -1310
18411  8 -0.001225 1384 -1383 -1309
18412  8 -0.001225 1384 -1383 -1308
18413  8 -0.001225 1384 -1383 -1307
18414  8 -0.001225 1384 -1383 -1306
18415  8 -0.001225 1384 -1383 -1305
18416  8 -0.001225 1384 -1383 -1304
18417  8 -0.001225 1384 -1383 -1303
18418  8 -0.001225 1384 -1383 -1302
18419  8 -0.001225 1384 -1383 -1301
c 8 cm off bottom of lazy susan sample
18420  8 -0.001225 1383 -1382 -1340
18421  8 -0.001225 1383 -1382 -1339
18422  8 -0.001225 1383 -1382 -1338
18423  8 -0.001225 1383 -1382 -1337
18424  8 -0.001225 1383 -1382 -1336
18425  8 -0.001225 1383 -1382 -1335
18426  8 -0.001225 1383 -1382 -1334
18427  8 -0.001225 1383 -1382 -1333
18428  8 -0.001225 1383 -1382 -1332
18429  8 -0.001225 1383 -1382 -1331
18430  8 -0.001225 1383 -1382 -1330
18431  8 -0.001225 1383 -1382 -1329
18432  8 -0.001225 1383 -1382 -1328
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18433  8 -0.001225 1383 -1382 -1327
18434  8 -0.001225 1383 -1382 -1326
18435  8 -0.001225 1383 -1382 -1325
18436  8 -0.001225 1383 -1382 -1324
18437  8 -0.001225 1383 -1382 -1323
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18439  8 -0.001225 1383 -1382 -1321
18440  8 -0.001225 1383 -1382 -1320
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18442  8 -0.001225 1383 -1382 -1318
18443  8 -0.001225 1383 -1382 -1317
18444  8 -0.001225 1383 -1382 -1316
18445  8 -0.001225 1383 -1382 -1315
18446  8 -0.001225 1383 -1382 -1314
18447  8 -0.001225 1383 -1382 -1313
18448  8 -0.001225 1383 -1382 -1312
18449  8 -0.001225 1383 -1382 -1311
18450  8 -0.001225 1383 -1382 -1310
18451  8 -0.001225 1383 -1382 -1309
18452  8 -0.001225 1383 -1382 -1308
18453  8 -0.001225 1383 -1382 -1307
18454  8 -0.001225 1383 -1382 -1306
18455  8 -0.001225 1383 -1382 -1305
18456  8 -0.001225 1383 -1382 -1304
18457  8 -0.001225 1383 -1382 -1303
18458  8 -0.001225 1383 -1382 -1302
18459  8 -0.001225 1383 -1382 -1301
c 9 cm off bottom of lazy susan sample
18460  8 -0.001225 1382 -1381 -1340
18461  8 -0.001225 1382 -1381 -1339
18462  8 -0.001225 1382 -1381 -1338
18463  8 -0.001225 1382 -1381 -1337
18464  8 -0.001225 1382 -1381 -1336
18465  8 -0.001225 1382 -1381 -1335
18466  8 -0.001225 1382 -1381 -1334
18467  8 -0.001225 1382 -1381 -1333
18468  8 -0.001225 1382 -1381 -1332
18469  8 -0.001225 1382 -1381 -1331
18470  8 -0.001225 1382 -1381 -1330
18471  8 -0.001225 1382 -1381 -1329
18472  8 -0.001225 1382 -1381 -1328
18473  8 -0.001225 1382 -1381 -1327
18474  8 -0.001225 1382 -1381 -1326
18475  8 -0.001225 1382 -1381 -1325
18476  8 -0.001225 1382 -1381 -1324
18477  8 -0.001225 1382 -1381 -1323
18478  8 -0.001225 1382 -1381 -1322
18479  8 -0.001225 1382 -1381 -1321
18480  8 -0.001225 1382 -1381 -1320
18481  8 -0.001225 1382 -1381 -1319
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18482  8 -0.001225 1382 -1381 -1318
18483  8 -0.001225 1382 -1381 -1317
18484  8 -0.001225 1382 -1381 -1316
18485  8 -0.001225 1382 -1381 -1315
18486  8 -0.001225 1382 -1381 -1314
18487  8 -0.001225 1382 -1381 -1313
18488  8 -0.001225 1382 -1381 -1312
18489  8 -0.001225 1382 -1381 -1311
18490  8 -0.001225 1382 -1381 -1310
18491  8 -0.001225 1382 -1381 -1309
18492  8 -0.001225 1382 -1381 -1308
18493  8 -0.001225 1382 -1381 -1307
18494  8 -0.001225 1382 -1381 -1306
18495  8 -0.001225 1382 -1381 -1305
18496  8 -0.001225 1382 -1381 -1304
18497  8 -0.001225 1382 -1381 -1303
18498  8 -0.001225 1382 -1381 -1302
18499  8 -0.001225 1382 -1381 -1301
c Grid Locations
20101 LIKE 40019 BUT u=201  $ H2O
20102 LIKE 40020 BUT u=201  $ Cladding
20103 LIKE 40021 BUT u=201  $ Zirc pin
20104 LIKE 40022 BUT mat=2985 rho=-6.0124 vol=128.49 u=201 $ Slug 1
20105 LIKE 40023 BUT mat=2985 rho=-6.0124 vol=128.49 u=201 $ Slug 2
20106 LIKE 40024 BUT mat=2985 rho=-6.0124 vol=128.49 u=201 $ Slug 3
c
20201 LIKE 40019 BUT u=202  $ H2O
20202 LIKE 40020 BUT u=202  $ Cladding
20203 LIKE 40021 BUT u=202  $ Zirc pin
20204 LIKE 40022 BUT mat=3384 rho=-6.0124 vol=128.49 u=202 $ Slug 1
20205 LIKE 40023 BUT mat=3384 rho=-6.0124 vol=128.49 u=202 $ Slug 2
20206 LIKE 40024 BUT mat=3384 rho=-6.0124 vol=128.49 u=202 $ Slug 3
c
20301 LIKE 40019 BUT u=203  $ H2O
20302 LIKE 40020 BUT u=203  $ Cladding
20303 LIKE 40021 BUT u=203  $ Zirc pin
20304 LIKE 40022 BUT mat=9878 rho=-6.0124 vol=128.49 u=203 $ Slug 1
20305 LIKE 40023 BUT mat=9878 rho=-6.0124 vol=128.49 u=203 $ Slug 2
20306 LIKE 40024 BUT mat=9878 rho=-6.0124 vol=128.49 u=203 $ Slug 3
c
20401 LIKE 40019 BUT u=204  $ H2O
20402 LIKE 40020 BUT u=204  $ Cladding
20403 LIKE 40021 BUT u=204  $ Zirc pin
20404 LIKE 40022 BUT mat=3013 rho=-6.0124 vol=128.49 u=204 $ Slug 1
20405 LIKE 40023 BUT mat=3013 rho=-6.0124 vol=128.49 u=204 $ Slug 2
20406 LIKE 40024 BUT mat=3013 rho=-6.0124 vol=128.49 u=204 $ Slug 3
c
20501 LIKE 40019 BUT u=205  $ H2O
20502 LIKE 40020 BUT u=205  $ Cladding
20503 LIKE 40021 BUT u=205  $ Zirc pin
```

```
20504 LIKE 40022 BUT mat=2899 rho=-6.0124 vol=128.49 u=205 $ Slug 1
20505 LIKE 40023 BUT mat=2899 rho=-6.0124 vol=128.49 u=205 $ Slug 2
20506 LIKE 40024 BUT mat=2899 rho=-6.0124 vol=128.49 u=205 $ Slug 3
c
20601 LIKE 40019 BUT u=206  $ H2O
20602 LIKE 40020 BUT u=206  $ Cladding
20603 LIKE 40021 BUT u=206  $ Zirc pin
20604 LIKE 40022 BUT mat=9809 rho=-6.0124 vol=128.49 u=206 $ Slug 1
20605 LIKE 40023 BUT mat=9809 rho=-6.0124 vol=128.49 u=206 $ Slug 2
20606 LIKE 40024 BUT mat=9809 rho=-6.0124 vol=128.49 u=206 $ Slug 3
c
c C01 is the Trans Rod
c
30201 LIKE 40019 BUT u=302  $ H2O
30202 LIKE 40020 BUT u=302  $ Cladding
30203 LIKE 40021 BUT u=302  $ Zirc pin
30204 LIKE 40022 BUT mat=2965 rho=-6.0124 vol=128.49 u=302 $ Slug 1
30205 LIKE 40023 BUT mat=2965 rho=-6.0124 vol=128.49 u=302 $ Slug 2
30206 LIKE 40024 BUT mat=2965 rho=-6.0124 vol=128.49 u=302 $ Slug 3
c
30301 LIKE 40019 BUT u=303  $ H2O
30302 LIKE 40020 BUT u=303  $ Cladding
30303 LIKE 40021 BUT u=303  $ Zirc pin
30304 LIKE 40022 BUT mat=2984 rho=-6.0124 vol=128.49 u=303 $ Slug 1
30305 LIKE 40023 BUT mat=2984 rho=-6.0124 vol=128.49 u=303 $ Slug 2
30306 LIKE 40024 BUT mat=2984 rho=-6.0124 vol=128.49 u=303 $ Slug 3
c
30401 LIKE 40019 BUT u=304  $ H2O
30402 LIKE 40020 BUT u=304  $ Cladding
30403 LIKE 40021 BUT u=304  $ Zirc pin
30404 LIKE 40022 BUT mat=2944 rho=-6.0124 vol=128.49 u=304 $ Slug 1
30405 LIKE 40023 BUT mat=2944 rho=-6.0124 vol=128.49 u=304 $ Slug 2
30406 LIKE 40024 BUT mat=2944 rho=-6.0124 vol=128.49 u=304 $ Slug 3
c
30501 LIKE 40019 BUT u=305  $ H2O
30502 LIKE 40020 BUT u=305  $ Cladding
30503 LIKE 40021 BUT u=305  $ Zirc pin
30504 LIKE 40022 BUT mat=2931 rho=-6.0124 vol=128.49 u=305 $ Slug 1
30505 LIKE 40023 BUT mat=2931 rho=-6.0124 vol=128.49 u=305 $ Slug 2
30506 LIKE 40024 BUT mat=2931 rho=-6.0124 vol=128.49 u=305 $ Slug 3
c
30601 LIKE 40019 BUT u=306  $ H2O
30602 LIKE 40020 BUT u=306  $ Cladding
30603 LIKE 40021 BUT u=306  $ Zirc pin
30604 LIKE 40022 BUT mat=2983 rho=-6.0124 vol=128.49 u=306 $ Slug 1
30605 LIKE 40023 BUT mat=2983 rho=-6.0124 vol=128.49 u=306 $ Slug 2
30606 LIKE 40024 BUT mat=2983 rho=-6.0124 vol=128.49 u=306 $ Slug 3
c
c C07 is the Reg Rod
c
```

```
30801 LIKE 40019 BUT u=308  $ H2O
30802 LIKE 40020 BUT u=308  $ Cladding
30803 LIKE 40021 BUT u=308  $ Zirc pin
30804 LIKE 40022 BUT mat=2980 rho=-6.0124 vol=128.49 u=308 $ Slug 1
30805 LIKE 40023 BUT mat=2980 rho=-6.0124 vol=128.49 u=308 $ Slug 2
30806 LIKE 40024 BUT mat=2980 rho=-6.0124 vol=128.49 u=308 $ Slug 3
c
30901 LIKE 40019 BUT u=309  $ H2O
30902 LIKE 40020 BUT u=309  $ Cladding
30903 LIKE 40021 BUT u=309  $ Zirc pin
30904 LIKE 40022 BUT mat=2925 rho=-6.0124 vol=128.49 u=309 $ Slug 1
30905 LIKE 40023 BUT mat=2925 rho=-6.0124 vol=128.49 u=309 $ Slug 2
30906 LIKE 40024 BUT mat=2925 rho=-6.0124 vol=128.49 u=309 $ Slug 3
c
31001 LIKE 40019 BUT u=310  $ H2O
31002 LIKE 40020 BUT u=310  $ Cladding
31003 LIKE 40021 BUT u=310  $ Zirc pin
31004 LIKE 40022 BUT mat=2941 rho=-6.0124 vol=128.49 u=310 $ Slug 1
31005 LIKE 40023 BUT mat=2941 rho=-6.0124 vol=128.49 u=310 $ Slug 2
31006 LIKE 40024 BUT mat=2941 rho=-6.0124 vol=128.49 u=310 $ Slug 3
c
31101 LIKE 40019 BUT u=311  $ H2O
31102 LIKE 40020 BUT u=311  $ Cladding
31103 LIKE 40021 BUT u=311  $ Zirc pin
31104 LIKE 40022 BUT mat=2979 rho=-6.0124 vol=128.49 u=311 $ Slug 1
31105 LIKE 40023 BUT mat=2979 rho=-6.0124 vol=128.49 u=311 $ Slug 2
31106 LIKE 40024 BUT mat=2979 rho=-6.0124 vol=128.49 u=311 $ Slug 3
c
31201 LIKE 40019 BUT u=312  $ H2O
31202 LIKE 40020 BUT u=312  $ Cladding
31203 LIKE 40021 BUT u=312  $ Zirc pin
31204 LIKE 40022 BUT mat=2964 rho=-6.0124 vol=128.49 u=312 $ Slug 1
31205 LIKE 40023 BUT mat=2964 rho=-6.0124 vol=128.49 u=312 $ Slug 2
31206 LIKE 40024 BUT mat=2964 rho=-6.0124 vol=128.49 u=312 $ Slug 3
c
40101 LIKE 40019 BUT u=401  $ H2O
40102 LIKE 40020 BUT u=401  $ Cladding
40103 LIKE 40021 BUT u=401  $ Zirc pin
40104 LIKE 40022 BUT mat=2910 rho=-6.0124 vol=128.49 u=401 $ Slug 1
40105 LIKE 40023 BUT mat=2910 rho=-6.0124 vol=128.49 u=401 $ Slug 2
40106 LIKE 40024 BUT mat=2910 rho=-6.0124 vol=128.49 u=401 $ Slug 3
c
40201 LIKE 40019 BUT u=402  $ H2O
40202 LIKE 40020 BUT u=402  $ Cladding
40203 LIKE 40021 BUT u=402  $ Zirc pin
40204 LIKE 40022 BUT mat=2959 rho=-6.0124 vol=128.49 u=402 $ Slug 1
40205 LIKE 40023 BUT mat=2959 rho=-6.0124 vol=128.49 u=402 $ Slug 2
40206 LIKE 40024 BUT mat=2959 rho=-6.0124 vol=128.49 u=402 $ Slug 3
c
40301 LIKE 40019 BUT u=403  $ H2O
```

```
40302 LIKE 40020 BUT u=403  $ Cladding
40303 LIKE 40021 BUT u=403  $ Zirc pin
40304 LIKE 40022 BUT mat=2906 rho=-6.0124 vol=128.49 u=403 $ Slug 1
40305 LIKE 40023 BUT mat=2906 rho=-6.0124 vol=128.49 u=403 $ Slug 2
40306 LIKE 40024 BUT mat=2906 rho=-6.0124 vol=128.49 u=403 $ Slug 3
c
40401 LIKE 40019 BUT u=404  $ H2O
40402 LIKE 40020 BUT u=404  $ Cladding
40403 LIKE 40021 BUT u=404  $ Zirc pin
40404 LIKE 40022 BUT mat=2992 rho=-6.0124 vol=128.49 u=404 $ Slug 1
40405 LIKE 40023 BUT mat=2992 rho=-6.0124 vol=128.49 u=404 $ Slug 2
40406 LIKE 40024 BUT mat=2992 rho=-6.0124 vol=128.49 u=404 $ Slug 3
c
40501 LIKE 40019 BUT u=405  $ H2O
40502 LIKE 40020 BUT u=405  $ Cladding
40503 LIKE 40021 BUT u=405  $ Zirc pin
40504 LIKE 40022 BUT mat=2962 rho=-6.0124 vol=128.49 u=405 $ Slug 1
40505 LIKE 40023 BUT mat=2962 rho=-6.0124 vol=128.49 u=405 $ Slug 2
40506 LIKE 40024 BUT mat=2962 rho=-6.0124 vol=128.49 u=405 $ Slug 3
c
c D06 is the Shim 1 Rod
c
40701 LIKE 40019 BUT u=407  $ H2O
40702 LIKE 40020 BUT u=407  $ Cladding
40703 LIKE 40021 BUT u=407  $ Zirc pin
40704 LIKE 40022 BUT mat=2928 rho=-6.0124 vol=128.49 u=407 $ Slug 1
40705 LIKE 40023 BUT mat=2928 rho=-6.0124 vol=128.49 u=407 $ Slug 2
40706 LIKE 40024 BUT mat=2928 rho=-6.0124 vol=128.49 u=407 $ Slug 3
c
40801 LIKE 40019 BUT u=408  $ H2O
40802 LIKE 40020 BUT u=408  $ Cladding
40803 LIKE 40021 BUT u=408  $ Zirc pin
40804 LIKE 40022 BUT mat=2939 rho=-6.0124 vol=128.49 u=408 $ Slug 1
40805 LIKE 40023 BUT mat=2939 rho=-6.0124 vol=128.49 u=408 $ Slug 2
40806 LIKE 40024 BUT mat=2939 rho=-6.0124 vol=128.49 u=408 $ Slug 3
c
40901 LIKE 40019 BUT u=409  $ H2O
40902 LIKE 40020 BUT u=409  $ Cladding
40903 LIKE 40021 BUT u=409  $ Zirc pin
40904 LIKE 40022 BUT mat=5918 rho=-6.0124 vol=128.49 u=409 $ Slug 1
40905 LIKE 40023 BUT mat=5918 rho=-6.0124 vol=128.49 u=409 $ Slug 2
40906 LIKE 40024 BUT mat=5918 rho=-6.0124 vol=128.49 u=409 $ Slug 3
c
41001 LIKE 40019 BUT u=410  $ H2O
41002 LIKE 40020 BUT u=410  $ Cladding
41003 LIKE 40021 BUT u=410  $ Zirc pin
41004 LIKE 40022 BUT mat=2977 rho=-6.0124 vol=128.49 u=410 $ Slug 1
41005 LIKE 40023 BUT mat=2977 rho=-6.0124 vol=128.49 u=410 $ Slug 2
41006 LIKE 40024 BUT mat=2977 rho=-6.0124 vol=128.49 u=410 $ Slug 3
c
```

```
41101 LIKE 40019 BUT u=411  $ H2O
41102 LIKE 40020 BUT u=411  $ Cladding
41103 LIKE 40021 BUT u=411  $ Zirc pin
41104 LIKE 40022 BUT mat=2974 rho=-6.0124 vol=128.49 u=411 $ Slug 1
41105 LIKE 40023 BUT mat=2974 rho=-6.0124 vol=128.49 u=411 $ Slug 2
41106 LIKE 40024 BUT mat=2974 rho=-6.0124 vol=128.49 u=411 $ Slug 3
c
41201 LIKE 40019 BUT u=412  $ H2O
41202 LIKE 40020 BUT u=412  $ Cladding
41203 LIKE 40021 BUT u=412  $ Zirc pin
41204 LIKE 40022 BUT mat=2905 rho=-6.0124 vol=128.49 u=412 $ Slug 1
41205 LIKE 40023 BUT mat=2905 rho=-6.0124 vol=128.49 u=412 $ Slug 2
41206 LIKE 40024 BUT mat=2905 rho=-6.0124 vol=128.49 u=412 $ Slug 3
c
41301 LIKE 40019 BUT u=413  $ H2O
41302 LIKE 40020 BUT u=413  $ Cladding
41303 LIKE 40021 BUT u=413  $ Zirc pin
41304 LIKE 40022 BUT mat=2943 rho=-6.0124 vol=128.49 u=413 $ Slug 1
41305 LIKE 40023 BUT mat=2943 rho=-6.0124 vol=128.49 u=413 $ Slug 2
41306 LIKE 40024 BUT mat=2943 rho=-6.0124 vol=128.49 u=413 $ Slug 3
c
c D14 is the Shim 2 Rod
c
41501 LIKE 40019 BUT u=415  $ H2O
41502 LIKE 40020 BUT u=415  $ Cladding
41503 LIKE 40021 BUT u=415  $ Zirc pin
41504 LIKE 40022 BUT mat=2950 rho=-6.0124 vol=128.49 u=415 $ Slug 1
41505 LIKE 40023 BUT mat=2950 rho=-6.0124 vol=128.49 u=415 $ Slug 2
41506 LIKE 40024 BUT mat=2950 rho=-6.0124 vol=128.49 u=415 $ Slug 3
c
41601 LIKE 40019 BUT u=416  $ H2O
41602 LIKE 40020 BUT u=416  $ Cladding
41603 LIKE 40021 BUT u=416  $ Zirc pin
41604 LIKE 40022 BUT mat=2929 rho=-6.0124 vol=128.49 u=416 $ Slug 1
41605 LIKE 40023 BUT mat=2929 rho=-6.0124 vol=128.49 u=416 $ Slug 2
41606 LIKE 40024 BUT mat=2929 rho=-6.0124 vol=128.49 u=416 $ Slug 3
c
41701 LIKE 40019 BUT u=417  $ H2O
41702 LIKE 40020 BUT u=417  $ Cladding
41703 LIKE 40021 BUT u=417  $ Zirc pin
41704 LIKE 40022 BUT mat=2955 rho=-6.0124 vol=128.49 u=417 $ Slug 1
41705 LIKE 40023 BUT mat=2955 rho=-6.0124 vol=128.49 u=417 $ Slug 2
41706 LIKE 40024 BUT mat=2955 rho=-6.0124 vol=128.49 u=417 $ Slug 3
c
41801 LIKE 40019 BUT u=418  $ H2O
41802 LIKE 40020 BUT u=418  $ Cladding
41803 LIKE 40021 BUT u=418  $ Zirc pin
41804 LIKE 40022 BUT mat=2975 rho=-6.0124 vol=128.49 u=418 $ Slug 1
41805 LIKE 40023 BUT mat=2975 rho=-6.0124 vol=128.49 u=418 $ Slug 2
41806 LIKE 40024 BUT mat=2975 rho=-6.0124 vol=128.49 u=418 $ Slug 3
```

```
c
50101 LIKE 40019 BUT u=501  $ H2O
50102 LIKE 40020 BUT u=501  $ Cladding
50103 LIKE 40021 BUT u=501  $ Zirc pin
50104 LIKE 40022 BUT mat=5845 rho=-6.0124 vol=128.49 u=501 $ Slug 1
50105 LIKE 40023 BUT mat=5845 rho=-6.0124 vol=128.49 u=501 $ Slug 2
50106 LIKE 40024 BUT mat=5845 rho=-6.0124 vol=128.49 u=501 $ Slug 3
c
50201 LIKE 40019 BUT u=502  $ H2O
50202 LIKE 40020 BUT u=502  $ Cladding
50203 LIKE 40021 BUT u=502  $ Zirc pin
50204 LIKE 40022 BUT mat=6932 rho=-6.0124 vol=128.49 u=502 $ Slug 1
50205 LIKE 40023 BUT mat=6932 rho=-6.0124 vol=128.49 u=502 $ Slug 2
50206 LIKE 40024 BUT mat=6932 rho=-6.0124 vol=128.49 u=502 $ Slug 3
c
50301 LIKE 40019 BUT u=503  $ H2O
50302 LIKE 40020 BUT u=503  $ Cladding
50303 LIKE 40021 BUT u=503  $ Zirc pin
50304 LIKE 40022 BUT mat=2932 rho=-6.0124 vol=128.49 u=503 $ Slug 1
50305 LIKE 40023 BUT mat=2932 rho=-6.0124 vol=128.49 u=503 $ Slug 2
50306 LIKE 40024 BUT mat=2932 rho=-6.0124 vol=128.49 u=503 $ Slug 3
c
50401 LIKE 40019 BUT u=504  $ H2O
50402 LIKE 40020 BUT u=504  $ Cladding
50403 LIKE 40021 BUT u=504  $ Zirc pin
50404 LIKE 40022 BUT mat=5915 rho=-6.0124 vol=128.49 u=504 $ Slug 1
50405 LIKE 40023 BUT mat=5915 rho=-6.0124 vol=128.49 u=504 $ Slug 2
50406 LIKE 40024 BUT mat=5915 rho=-6.0124 vol=128.49 u=504 $ Slug 3
c
50501 LIKE 40019 BUT u=505  $ H2O
50502 LIKE 40020 BUT u=505  $ Cladding
50503 LIKE 40021 BUT u=505  $ Zirc pin
50504 LIKE 40022 BUT mat=6886 rho=-6.0124 vol=128.49 u=505 $ Slug 1
50505 LIKE 40023 BUT mat=6886 rho=-6.0124 vol=128.49 u=505 $ Slug 2
50506 LIKE 40024 BUT mat=6886 rho=-6.0124 vol=128.49 u=505 $ Slug 3
c
50601 LIKE 40019 BUT u=506  $ H2O
50602 LIKE 40020 BUT u=506  $ Cladding
50603 LIKE 40021 BUT u=506  $ Zirc pin
50604 LIKE 40022 BUT mat=5912 rho=-6.0124 vol=128.49 u=506 $ Slug 1
50605 LIKE 40023 BUT mat=5912 rho=-6.0124 vol=128.49 u=506 $ Slug 2
50606 LIKE 40024 BUT mat=5912 rho=-6.0124 vol=128.49 u=506 $ Slug 3
c
50701 LIKE 40019 BUT u=507  $ H2O
50702 LIKE 40020 BUT u=507  $ Cladding
50703 LIKE 40021 BUT u=507  $ Zirc pin
50704 LIKE 40022 BUT mat=5846 rho=-6.0124 vol=128.49 u=507 $ Slug 1
50705 LIKE 40023 BUT mat=5846 rho=-6.0124 vol=128.49 u=507 $ Slug 2
50706 LIKE 40024 BUT mat=5846 rho=-6.0124 vol=128.49 u=507 $ Slug 3
c
```

```
50801 LIKE 40019 BUT u=508  $ H2O
50802 LIKE 40020 BUT u=508  $ Cladding
50803 LIKE 40021 BUT u=508  $ Zirc pin
50804 LIKE 40022 BUT mat=5903 rho=-6.0124 vol=128.49 u=508 $ Slug 1
50805 LIKE 40023 BUT mat=5903 rho=-6.0124 vol=128.49 u=508 $ Slug 2
50806 LIKE 40024 BUT mat=5903 rho=-6.0124 vol=128.49 u=508 $ Slug 3
c
50901 LIKE 40019 BUT u=509  $ H2O
50902 LIKE 40020 BUT u=509  $ Cladding
50903 LIKE 40021 BUT u=509  $ Zirc pin
50904 LIKE 40022 BUT mat=5917 rho=-6.0124 vol=128.49 u=509 $ Slug 1
50905 LIKE 40023 BUT mat=5917 rho=-6.0124 vol=128.49 u=509 $ Slug 2
50906 LIKE 40024 BUT mat=5917 rho=-6.0124 vol=128.49 u=509 $ Slug 3
c
51001 LIKE 40019 BUT u=510  $ H2O
51002 LIKE 40020 BUT u=510  $ Cladding
51003 LIKE 40021 BUT u=510  $ Zirc pin
51004 LIKE 40022 BUT mat=6929 rho=-6.0124 vol=128.49 u=510 $ Slug 1
51005 LIKE 40023 BUT mat=6929 rho=-6.0124 vol=128.49 u=510 $ Slug 2
51006 LIKE 40024 BUT mat=6929 rho=-6.0124 vol=128.49 u=510 $ Slug 3
c
51101 LIKE 40019 BUT u=511  $ H2O
51102 LIKE 40020 BUT u=511  $ Cladding
51103 LIKE 40021 BUT u=511  $ Zirc pin
51104 LIKE 40022 BUT mat=2932 rho=-6.0124 vol=128.49 u=511 $ Slug 1
51105 LIKE 40023 BUT mat=2932 rho=-6.0124 vol=128.49 u=511 $ Slug 2
51106 LIKE 40024 BUT mat=2932 rho=-6.0124 vol=128.49 u=511 $ Slug 3
c
51201 LIKE 40019 BUT u=512  $ H2O
51202 LIKE 40020 BUT u=512  $ Cladding
51203 LIKE 40021 BUT u=512  $ Zirc pin
51204 LIKE 40022 BUT mat=6925 rho=-6.0124 vol=128.49 u=512 $ Slug 1
51205 LIKE 40023 BUT mat=6925 rho=-6.0124 vol=128.49 u=512 $ Slug 2
51206 LIKE 40024 BUT mat=6925 rho=-6.0124 vol=128.49 u=512 $ Slug 3
c
51301 LIKE 40019 BUT u=513  $ H2O
51302 LIKE 40020 BUT u=513  $ Cladding
51303 LIKE 40021 BUT u=513  $ Zirc pin
51304 LIKE 40022 BUT mat=5844 rho=-6.0124 vol=128.49 u=513 $ Slug 1
51305 LIKE 40023 BUT mat=5844 rho=-6.0124 vol=128.49 u=513 $ Slug 2
51306 LIKE 40024 BUT mat=5844 rho=-6.0124 vol=128.49 u=513 $ Slug 3
c
51401 LIKE 40019 BUT u=514  $ H2O
51402 LIKE 40020 BUT u=514  $ Cladding
51403 LIKE 40021 BUT u=514  $ Zirc pin
51404 LIKE 40022 BUT mat=6923 rho=-6.0124 vol=128.49 u=514 $ Slug 1
51405 LIKE 40023 BUT mat=6923 rho=-6.0124 vol=128.49 u=514 $ Slug 2
51406 LIKE 40024 BUT mat=6923 rho=-6.0124 vol=128.49 u=514 $ Slug 3
c
51501 LIKE 40019 BUT u=515  $ H2O
```

```
51502 LIKE 40020 BUT u=515  $ Cladding
51503 LIKE 40021 BUT u=515  $ Zirc pin
51504 LIKE 40022 BUT mat=5919 rho=-6.0124 vol=128.49 u=515 $ Slug 1
51505 LIKE 40023 BUT mat=5919 rho=-6.0124 vol=128.49 u=515 $ Slug 2
51506 LIKE 40024 BUT mat=5919 rho=-6.0124 vol=128.49 u=515 $ Slug 3
c
51601 LIKE 40019 BUT u=516  $ H2O
51602 LIKE 40020 BUT u=516  $ Cladding
51603 LIKE 40021 BUT u=516  $ Zirc pin
51604 LIKE 40022 BUT mat=5921 rho=-6.0124 vol=128.49 u=516 $ Slug 1
51605 LIKE 40023 BUT mat=5921 rho=-6.0124 vol=128.49 u=516 $ Slug 2
51606 LIKE 40024 BUT mat=5921 rho=-6.0124 vol=128.49 u=516 $ Slug 3
c
51701 LIKE 40019 BUT u=517  $ H2O
51702 LIKE 40020 BUT u=517  $ Cladding
51703 LIKE 40021 BUT u=517  $ Zirc pin
51704 LIKE 40022 BUT mat=6927 rho=-6.0124 vol=128.49 u=517 $ Slug 1
51705 LIKE 40023 BUT mat=6927 rho=-6.0124 vol=128.49 u=517 $ Slug 2
51706 LIKE 40024 BUT mat=6927 rho=-6.0124 vol=128.49 u=517 $ Slug 3
c
51801 LIKE 40019 BUT u=518  $ H2O
51802 LIKE 40020 BUT u=518  $ Cladding
51803 LIKE 40021 BUT u=518  $ Zirc pin
51804 LIKE 40022 BUT mat=5902 rho=-6.0124 vol=128.49 u=518 $ Slug 1
51805 LIKE 40023 BUT mat=5902 rho=-6.0124 vol=128.49 u=518 $ Slug 2
51806 LIKE 40024 BUT mat=5902 rho=-6.0124 vol=128.49 u=518 $ Slug 3
c
51901 LIKE 40019 BUT u=519  $ H2O
51902 LIKE 40020 BUT u=519  $ Cladding
51903 LIKE 40021 BUT u=519  $ Zirc pin
51904 LIKE 40022 BUT mat=5904 rho=-6.0124 vol=128.49 u=519 $ Slug 1
51905 LIKE 40023 BUT mat=5904 rho=-6.0124 vol=128.49 u=519 $ Slug 2
51906 LIKE 40024 BUT mat=5904 rho=-6.0124 vol=128.49 u=519 $ Slug 3
c
52001 LIKE 40019 BUT u=520  $ H2O
52002 LIKE 40020 BUT u=520  $ Cladding
52003 LIKE 40021 BUT u=520  $ Zirc pin
52004 LIKE 40022 BUT mat=6930 rho=-6.0124 vol=128.49 u=520 $ Slug 1
52005 LIKE 40023 BUT mat=6930 rho=-6.0124 vol=128.49 u=520 $ Slug 2
52006 LIKE 40024 BUT mat=6930 rho=-6.0124 vol=128.49 u=520 $ Slug 3
c
52101 LIKE 40019 BUT u=521  $ H2O
52102 LIKE 40020 BUT u=521  $ Cladding
52103 LIKE 40021 BUT u=521  $ Zirc pin
52104 LIKE 40022 BUT mat=6889 rho=-6.0124 vol=128.49 u=521 $ Slug 1
52105 LIKE 40023 BUT mat=6889 rho=-6.0124 vol=128.49 u=521 $ Slug 2
52106 LIKE 40024 BUT mat=6889 rho=-6.0124 vol=128.49 u=521 $ Slug 3
c
52201 LIKE 40019 BUT u=522  $ H2O
52202 LIKE 40020 BUT u=522  $ Cladding
```

```
52203 LIKE 40021 BUT u=522  $ Zirc pin
52204 LIKE 40022 BUT mat=5914 rho=-6.0124 vol=128.49 u=522 $ Slug 1
52205 LIKE 40023 BUT mat=5914 rho=-6.0124 vol=128.49 u=522 $ Slug 2
52206 LIKE 40024 BUT mat=5914 rho=-6.0124 vol=128.49 u=522 $ Slug 3
c
52301 LIKE 40019 BUT u=523  $ H2O
52302 LIKE 40020 BUT u=523  $ Cladding
52303 LIKE 40021 BUT u=523  $ Zirc pin
52304 LIKE 40022 BUT mat=6142 rho=-6.0124 vol=128.49 u=523 $ Slug 1
52305 LIKE 40023 BUT mat=6142 rho=-6.0124 vol=128.49 u=523 $ Slug 2
52306 LIKE 40024 BUT mat=6142 rho=-6.0124 vol=128.49 u=523 $ Slug 3
c
52401 LIKE 40019 BUT u=524  $ H2O
52402 LIKE 40020 BUT u=524  $ Cladding
52403 LIKE 40021 BUT u=524  $ Zirc pin
52404 LIKE 40022 BUT mat=6928 rho=-6.0124 vol=128.49 u=524 $ Slug 1
52405 LIKE 40023 BUT mat=6928 rho=-6.0124 vol=128.49 u=524 $ Slug 2
52406 LIKE 40024 BUT mat=6928 rho=-6.0124 vol=128.49 u=524 $ Slug 3
c
60101 LIKE 40019 BUT u=601  $ H2O
60102 LIKE 40020 BUT u=601  $ Cladding
60103 LIKE 40021 BUT u=601  $ Zirc pin
60104 LIKE 40022 BUT mat=9817 rho=-6.0124 vol=128.49 u=601 $ Slug 1
60105 LIKE 40023 BUT mat=9817 rho=-6.0124 vol=128.49 u=601 $ Slug 2
60106 LIKE 40024 BUT mat=9817 rho=-6.0124 vol=128.49 u=601 $ Slug 3
c
60201 LIKE 40019 BUT u=602  $ H2O
60202 LIKE 40020 BUT u=602  $ Cladding
60203 LIKE 40021 BUT u=602  $ Zirc pin
60204 LIKE 40022 BUT mat=5911 rho=-6.0124 vol=128.49 u=602 $ Slug 1
60205 LIKE 40023 BUT mat=5911 rho=-6.0124 vol=128.49 u=602 $ Slug 2
60206 LIKE 40024 BUT mat=5911 rho=-6.0124 vol=128.49 u=602 $ Slug 3
c
60301 LIKE 40019 BUT u=603  $ H2O
60302 LIKE 40020 BUT u=603  $ Cladding
60303 LIKE 40021 BUT u=603  $ Zirc pin
60304 LIKE 40022 BUT mat=3496 rho=-6.0124 vol=128.49 u=603 $ Slug 1
60305 LIKE 40023 BUT mat=3496 rho=-6.0124 vol=128.49 u=603 $ Slug 2
60306 LIKE 40024 BUT mat=3496 rho=-6.0124 vol=128.49 u=603 $ Slug 3
c
60401 LIKE 40019 BUT u=604  $ H2O
60402 LIKE 40020 BUT u=604  $ Cladding
60403 LIKE 40021 BUT u=604  $ Zirc pin
60404 LIKE 40022 BUT mat=3504 rho=-6.0124 vol=128.49 u=604 $ Slug 1
60405 LIKE 40023 BUT mat=3504 rho=-6.0124 vol=128.49 u=604 $ Slug 2
60406 LIKE 40024 BUT mat=3504 rho=-6.0124 vol=128.49 u=604 $ Slug 3
c
60501 LIKE 40019 BUT u=605  $ H2O
60502 LIKE 40020 BUT u=605  $ Cladding
60503 LIKE 40021 BUT u=605  $ Zirc pin
```

```
60504 LIKE 40022 BUT mat=6931 rho=-6.0124 vol=128.49 u=605 $ Slug 1
60505 LIKE 40023 BUT mat=6931 rho=-6.0124 vol=128.49 u=605 $ Slug 2
60506 LIKE 40024 BUT mat=6931 rho=-6.0124 vol=128.49 u=605 $ Slug 3
c
60601 LIKE 40019 BUT u=606  $ H2O
60602 LIKE 40020 BUT u=606  $ Cladding
60603 LIKE 40021 BUT u=606  $ Zirc pin
60604 LIKE 40022 BUT mat=9816 rho=-6.0124 vol=128.49 u=606 $ Slug 1
60605 LIKE 40023 BUT mat=9816 rho=-6.0124 vol=128.49 u=606 $ Slug 2
60606 LIKE 40024 BUT mat=9816 rho=-6.0124 vol=128.49 u=606 $ Slug 3
c
60701 LIKE 40019 BUT u=607  $ H2O
60702 LIKE 40020 BUT u=607  $ Cladding
60703 LIKE 40021 BUT u=607  $ Zirc pin
60704 LIKE 40022 BUT mat=2915 rho=-6.0124 vol=128.49 u=607 $ Slug 1
60705 LIKE 40023 BUT mat=2915 rho=-6.0124 vol=128.49 u=607 $ Slug 2
60706 LIKE 40024 BUT mat=2915 rho=-6.0124 vol=128.49 u=607 $ Slug 3
c
60801 LIKE 40019 BUT u=608  $ H2O
60802 LIKE 40020 BUT u=608  $ Cladding
60803 LIKE 40021 BUT u=608  $ Zirc pin
60804 LIKE 40022 BUT mat=2946 rho=-6.0124 vol=128.49 u=608 $ Slug 1
60805 LIKE 40023 BUT mat=2946 rho=-6.0124 vol=128.49 u=608 $ Slug 2
60806 LIKE 40024 BUT mat=2946 rho=-6.0124 vol=128.49 u=608 $ Slug 3
c
60901 LIKE 40019 BUT u=609  $ H2O
60902 LIKE 40020 BUT u=609  $ Cladding
60903 LIKE 40021 BUT u=609  $ Zirc pin
60904 LIKE 40022 BUT mat=6924 rho=-6.0124 vol=128.49 u=609 $ Slug 1
60905 LIKE 40023 BUT mat=6924 rho=-6.0124 vol=128.49 u=609 $ Slug 2
60906 LIKE 40024 BUT mat=6924 rho=-6.0124 vol=128.49 u=609 $ Slug 3
c
61001 LIKE 40019 BUT u=610  $ H2O
61002 LIKE 40020 BUT u=610  $ Cladding
61003 LIKE 40021 BUT u=610  $ Zirc pin
61004 LIKE 40022 BUT mat=9812 rho=-6.0124 vol=128.49 u=610 $ Slug 1
61005 LIKE 40023 BUT mat=9812 rho=-6.0124 vol=128.49 u=610 $ Slug 2
61006 LIKE 40024 BUT mat=9812 rho=-6.0124 vol=128.49 u=610 $ Slug 3
c
61101 LIKE 40019 BUT u=611  $ H2O
61102 LIKE 40020 BUT u=611  $ Cladding
61103 LIKE 40021 BUT u=611  $ Zirc pin
61104 LIKE 40022 BUT mat=2958 rho=-6.0124 vol=128.49 u=611 $ Slug 1
61105 LIKE 40023 BUT mat=2958 rho=-6.0124 vol=128.49 u=611 $ Slug 2
61106 LIKE 40024 BUT mat=2958 rho=-6.0124 vol=128.49 u=611 $ Slug 3
c
61201 LIKE 40019 BUT u=612  $ H2O
61202 LIKE 40020 BUT u=612  $ Cladding
61203 LIKE 40021 BUT u=612  $ Zirc pin
61204 LIKE 40022 BUT mat=5913 rho=-6.0124 vol=128.49 u=612 $ Slug 1
```

```
61205 LIKE 40023 BUT mat=5913 rho=-6.0124 vol=128.49 u=612 $ Slug 2
61206 LIKE 40024 BUT mat=5913 rho=-6.0124 vol=128.49 u=612 $ Slug 3
c
61301 LIKE 40019 BUT u=613  $ H2O
61302 LIKE 40020 BUT u=613  $ Cladding
61303 LIKE 40021 BUT u=613  $ Zirc pin
61304 LIKE 40022 BUT mat=5915 rho=-6.0124 vol=128.49 u=613 $ Slug 1
61305 LIKE 40023 BUT mat=5915 rho=-6.0124 vol=128.49 u=613 $ Slug 2
61306 LIKE 40024 BUT mat=5915 rho=-6.0124 vol=128.49 u=613 $ Slug 3
c
61401 LIKE 40019 BUT u=614  $ H2O
61402 LIKE 40020 BUT u=614  $ Cladding
61403 LIKE 40021 BUT u=614  $ Zirc pin
61404 LIKE 40022 BUT mat=6931 rho=-6.0124 vol=128.49 u=614 $ Slug 1
61405 LIKE 40023 BUT mat=6931 rho=-6.0124 vol=128.49 u=614 $ Slug 2
61406 LIKE 40024 BUT mat=6931 rho=-6.0124 vol=128.49 u=614 $ Slug 3
c
61501 LIKE 40019 BUT u=615  $ H2O
61502 LIKE 40020 BUT u=615  $ Cladding
61503 LIKE 40021 BUT u=615  $ Zirc pin
61504 LIKE 40022 BUT mat=2902 rho=-6.0124 vol=128.49 u=615 $ Slug 1
61505 LIKE 40023 BUT mat=2902 rho=-6.0124 vol=128.49 u=615 $ Slug 2
61506 LIKE 40024 BUT mat=2902 rho=-6.0124 vol=128.49 u=615 $ Slug 3
c
61601 LIKE 40019 BUT u=616  $ H2O
61602 LIKE 40020 BUT u=616  $ Cladding
61603 LIKE 40021 BUT u=616  $ Zirc pin
61604 LIKE 40022 BUT mat=9813 rho=-6.0124 vol=128.49 u=616 $ Slug 1
61605 LIKE 40023 BUT mat=9813 rho=-6.0124 vol=128.49 u=616 $ Slug 2
61606 LIKE 40024 BUT mat=9813 rho=-6.0124 vol=128.49 u=616 $ Slug 3
c
61701 LIKE 40019 BUT u=617  $ H2O
61702 LIKE 40020 BUT u=617  $ Cladding
61703 LIKE 40021 BUT u=617  $ Zirc pin
61704 LIKE 40022 BUT mat=2912 rho=-6.0124 vol=128.49 u=617 $ Slug 1
61705 LIKE 40023 BUT mat=2912 rho=-6.0124 vol=128.49 u=617 $ Slug 2
61706 LIKE 40024 BUT mat=2912 rho=-6.0124 vol=128.49 u=617 $ Slug 3
c
61801 LIKE 40019 BUT u=618  $ H2O
61802 LIKE 40020 BUT u=618  $ Cladding
61803 LIKE 40021 BUT u=618  $ Zirc pin
61804 LIKE 40022 BUT mat=6143 rho=-6.0124 vol=128.49 u=618 $ Slug 1
61805 LIKE 40023 BUT mat=6143 rho=-6.0124 vol=128.49 u=618 $ Slug 2
61806 LIKE 40024 BUT mat=6143 rho=-6.0124 vol=128.49 u=618 $ Slug 3
c
61901 LIKE 40019 BUT u=619  $ H2O
61902 LIKE 40020 BUT u=619  $ Cladding
61903 LIKE 40021 BUT u=619  $ Zirc pin
61904 LIKE 40022 BUT mat=5916 rho=-6.0124 vol=128.49 u=619 $ Slug 1
61905 LIKE 40023 BUT mat=5916 rho=-6.0124 vol=128.49 u=619 $ Slug 2
```

```
61906 LIKE 40024 BUT mat=5916 rho=-6.0124 vol=128.49 u=619 $ Slug 3
c
62001 LIKE 40019 BUT u=620  $ H2O
62002 LIKE 40020 BUT u=620  $ Cladding
62003 LIKE 40021 BUT u=620  $ Zirc pin
62004 LIKE 40022 BUT mat=2940 rho=-6.0124 vol=128.49 u=620 $ Slug 1
62005 LIKE 40023 BUT mat=2940 rho=-6.0124 vol=128.49 u=620 $ Slug 2
62006 LIKE 40024 BUT mat=2940 rho=-6.0124 vol=128.49 u=620 $ Slug 3
c
62101 LIKE 40019 BUT u=621  $ H2O
62102 LIKE 40020 BUT u=621  $ Cladding
62103 LIKE 40021 BUT u=621  $ Zirc pin
62104 LIKE 40022 BUT mat=2971 rho=-6.0124 vol=128.49 u=621 $ Slug 1
62105 LIKE 40023 BUT mat=2971 rho=-6.0124 vol=128.49 u=621 $ Slug 2
62106 LIKE 40024 BUT mat=2971 rho=-6.0124 vol=128.49 u=621 $ Slug 3
c
62201 LIKE 40019 BUT u=622  $ H2O
62202 LIKE 40020 BUT u=622  $ Cladding
62203 LIKE 40021 BUT u=622  $ Zirc pin
62204 LIKE 40022 BUT mat=2969 rho=-6.0124 vol=128.49 u=622 $ Slug 1
62205 LIKE 40023 BUT mat=2969 rho=-6.0124 vol=128.49 u=622 $ Slug 2
62206 LIKE 40024 BUT mat=2969 rho=-6.0124 vol=128.49 u=622 $ Slug 3
c
62301 LIKE 40019 BUT u=623  $ H2O
62302 LIKE 40020 BUT u=623  $ Cladding
62303 LIKE 40021 BUT u=623  $ Zirc pin
62304 LIKE 40022 BUT mat=6926 rho=-6.0124 vol=128.49 u=623 $ Slug 1
62305 LIKE 40023 BUT mat=6926 rho=-6.0124 vol=128.49 u=623 $ Slug 2
62306 LIKE 40024 BUT mat=6926 rho=-6.0124 vol=128.49 u=623 $ Slug 3
c
62401 LIKE 40019 BUT u=624  $ H2O
62402 LIKE 40020 BUT u=624  $ Cladding
62403 LIKE 40021 BUT u=624  $ Zirc pin
62404 LIKE 40022 BUT mat=3513 rho=-6.0124 vol=128.49 u=624 $ Slug 1
62405 LIKE 40023 BUT mat=3513 rho=-6.0124 vol=128.49 u=624 $ Slug 2
62406 LIKE 40024 BUT mat=3513 rho=-6.0124 vol=128.49 u=624 $ Slug 3
c
62501 LIKE 40019 BUT u=625  $ H2O
62502 LIKE 40020 BUT u=625  $ Cladding
62503 LIKE 40021 BUT u=625  $ Zirc pin
62504 LIKE 40022 BUT mat=9811 rho=-6.0124 vol=128.49 u=625 $ Slug 1
62505 LIKE 40023 BUT mat=9811 rho=-6.0124 vol=128.49 u=625 $ Slug 2
62506 LIKE 40024 BUT mat=9811 rho=-6.0124 vol=128.49 u=625 $ Slug 3
c
62601 LIKE 40019 BUT u=626  $ H2O
62602 LIKE 40020 BUT u=626  $ Cladding
62603 LIKE 40021 BUT u=626  $ Zirc pin
62604 LIKE 40022 BUT mat=2960 rho=-6.0124 vol=128.49 u=626 $ Slug 1
62605 LIKE 40023 BUT mat=2960 rho=-6.0124 vol=128.49 u=626 $ Slug 2
62606 LIKE 40024 BUT mat=2960 rho=-6.0124 vol=128.49 u=626 $ Slug 3
```

```
c
62701 LIKE 40019 BUT u=627  $ H2O
62702 LIKE 40020 BUT u=627  $ Cladding
62703 LIKE 40021 BUT u=627  $ Zirc pin
62704 LIKE 40022 BUT mat=2947 rho=-6.0124 vol=128.49 u=627 $ Slug 1
62705 LIKE 40023 BUT mat=2947 rho=-6.0124 vol=128.49 u=627 $ Slug 2
62706 LIKE 40024 BUT mat=2947 rho=-6.0124 vol=128.49 u=627 $ Slug 3
c
62801 LIKE 40019 BUT u=628  $ H2O
62802 LIKE 40020 BUT u=628  $ Cladding
62803 LIKE 40021 BUT u=628  $ Zirc pin
62804 LIKE 40022 BUT mat=2911 rho=-6.0124 vol=128.49 u=628 $ Slug 1
62805 LIKE 40023 BUT mat=2911 rho=-6.0124 vol=128.49 u=628 $ Slug 2
62806 LIKE 40024 BUT mat=2911 rho=-6.0124 vol=128.49 u=628 $ Slug 3
c
62901 LIKE 40019 BUT u=629  $ H2O
62902 LIKE 40020 BUT u=629  $ Cladding
62903 LIKE 40021 BUT u=629  $ Zirc pin
62904 LIKE 40022 BUT mat=5922 rho=-6.0124 vol=128.49 u=629 $ Slug 1
62905 LIKE 40023 BUT mat=5922 rho=-6.0124 vol=128.49 u=629 $ Slug 2
62906 LIKE 40024 BUT mat=5922 rho=-6.0124 vol=128.49 u=629 $ Slug 3
c
63001 LIKE 40019 BUT u=630  $ H2O
63002 LIKE 40020 BUT u=630  $ Cladding
63003 LIKE 40021 BUT u=630  $ Zirc pin
63004 LIKE 40022 BUT mat=9814 rho=-6.0124 vol=128.49 u=630 $ Slug 1
63005 LIKE 40023 BUT mat=9814 rho=-6.0124 vol=128.49 u=630 $ Slug 2
63006 LIKE 40024 BUT mat=9814 rho=-6.0124 vol=128.49 u=630 $ Slug 3
c
70201 LIKE 40019 BUT u=702  $ H2O
70202 LIKE 40020 BUT u=702  $ Cladding
70203 LIKE 40021 BUT u=702  $ Zirc pin
70204 LIKE 40022 BUT mat=9704 rho=-6.0124 vol=128.49 u=702 $ Slug 1
70205 LIKE 40023 BUT mat=9704 rho=-6.0124 vol=128.49 u=702 $ Slug 2
70206 LIKE 40024 BUT mat=9704 rho=-6.0124 vol=128.49 u=702 $ Slug 3
c
70301 LIKE 40019 BUT u=703  $ H2O
70302 LIKE 40020 BUT u=703  $ Cladding
70303 LIKE 40021 BUT u=703  $ Zirc pin
70304 LIKE 40022 BUT mat=2908 rho=-6.0124 vol=128.49 u=703 $ Slug 1
70305 LIKE 40023 BUT mat=2908 rho=-6.0124 vol=128.49 u=703 $ Slug 2
70306 LIKE 40024 BUT mat=2908 rho=-6.0124 vol=128.49 u=703 $ Slug 3
c
70401 LIKE 40019 BUT u=704  $ H2O
70402 LIKE 40020 BUT u=704  $ Cladding
70403 LIKE 40021 BUT u=704  $ Zirc pin
70404 LIKE 40022 BUT mat=3700 rho=-6.0124 vol=128.49 u=704 $ Slug 1
70405 LIKE 40023 BUT mat=3700 rho=-6.0124 vol=128.49 u=704 $ Slug 2
70406 LIKE 40024 BUT mat=3700 rho=-6.0124 vol=128.49 u=704 $ Slug 3
c
```

```
70501 LIKE 40019 BUT u=705  $ H2O
70502 LIKE 40020 BUT u=705  $ Cladding
70503 LIKE 40021 BUT u=705  $ Zirc pin
70504 LIKE 40022 BUT mat=3703 rho=-6.0124 vol=128.49 u=705 $ Slug 1
70505 LIKE 40023 BUT mat=3703 rho=-6.0124 vol=128.49 u=705 $ Slug 2
70506 LIKE 40024 BUT mat=3703 rho=-6.0124 vol=128.49 u=705 $ Slug 3
c
70601 LIKE 40019 BUT u=706  $ H2O
70602 LIKE 40020 BUT u=706  $ Cladding
70603 LIKE 40021 BUT u=706  $ Zirc pin
70604 LIKE 40022 BUT mat=5920 rho=-6.0124 vol=128.49 u=706 $ Slug 1
70605 LIKE 40023 BUT mat=5920 rho=-6.0124 vol=128.49 u=706 $ Slug 2
70606 LIKE 40024 BUT mat=5920 rho=-6.0124 vol=128.49 u=706 $ Slug 3
c
70801 LIKE 40019 BUT u=708  $ H2O
70802 LIKE 40020 BUT u=708  $ Cladding
70803 LIKE 40021 BUT u=708  $ Zirc pin
70804 LIKE 40022 BUT mat=9701 rho=-6.0124 vol=128.49 u=708 $ Slug 1
70805 LIKE 40023 BUT mat=9701 rho=-6.0124 vol=128.49 u=708 $ Slug 2
70806 LIKE 40024 BUT mat=9701 rho=-6.0124 vol=128.49 u=708 $ Slug 3
c
70901 LIKE 40019 BUT u=709  $ H2O
70902 LIKE 40020 BUT u=709  $ Cladding
70903 LIKE 40021 BUT u=709  $ Zirc pin
70904 LIKE 40022 BUT mat=2957 rho=-6.0124 vol=128.49 u=709 $ Slug 1
70905 LIKE 40023 BUT mat=2957 rho=-6.0124 vol=128.49 u=709 $ Slug 2
70906 LIKE 40024 BUT mat=2957 rho=-6.0124 vol=128.49 u=709 $ Slug 3
c
71001 LIKE 40019 BUT u=710  $ H2O
71002 LIKE 40020 BUT u=710  $ Cladding
71003 LIKE 40021 BUT u=710  $ Zirc pin
71004 LIKE 40022 BUT mat=2938 rho=-6.0124 vol=128.49 u=710 $ Slug 1
71005 LIKE 40023 BUT mat=2938 rho=-6.0124 vol=128.49 u=710 $ Slug 2
71006 LIKE 40024 BUT mat=2938 rho=-6.0124 vol=128.49 u=710 $ Slug 3
c
71101 LIKE 40019 BUT u=711  $ H2O
71102 LIKE 40020 BUT u=711  $ Cladding
71103 LIKE 40021 BUT u=711  $ Zirc pin
71104 LIKE 40022 BUT mat=2927 rho=-6.0124 vol=128.49 u=711 $ Slug 1
71105 LIKE 40023 BUT mat=2927 rho=-6.0124 vol=128.49 u=711 $ Slug 2
71106 LIKE 40024 BUT mat=2927 rho=-6.0124 vol=128.49 u=711 $ Slug 3
c
71201 LIKE 40019 BUT u=712  $ H2O
71202 LIKE 40020 BUT u=712  $ Cladding
71203 LIKE 40021 BUT u=712  $ Zirc pin
71204 LIKE 40022 BUT mat=9702 rho=-6.0124 vol=128.49 u=712 $ Slug 1
71205 LIKE 40023 BUT mat=9702 rho=-6.0124 vol=128.49 u=712 $ Slug 2
71206 LIKE 40024 BUT mat=9702 rho=-6.0124 vol=128.49 u=712 $ Slug 3
c
71401 LIKE 40019 BUT u=714  $ H2O
```

```
71402 LIKE 40020 BUT u=714  $ Cladding
71403 LIKE 40021 BUT u=714  $ Zirc pin
71404 LIKE 40022 BUT mat=2970 rho=-6.0124 vol=128.49 u=714 $ Slug 1
71405 LIKE 40023 BUT mat=2970 rho=-6.0124 vol=128.49 u=714 $ Slug 2
71406 LIKE 40024 BUT mat=2970 rho=-6.0124 vol=128.49 u=714 $ Slug 3
c
71501 LIKE 40019 BUT u=715  $ H2O
71502 LIKE 40020 BUT u=715  $ Cladding
71503 LIKE 40021 BUT u=715  $ Zirc pin
71504 LIKE 40022 BUT mat=2976 rho=-6.0124 vol=128.49 u=715 $ Slug 1
71505 LIKE 40023 BUT mat=2976 rho=-6.0124 vol=128.49 u=715 $ Slug 2
71506 LIKE 40024 BUT mat=2976 rho=-6.0124 vol=128.49 u=715 $ Slug 3
c
71601 LIKE 40019 BUT u=716  $ H2O
71602 LIKE 40020 BUT u=716  $ Cladding
71603 LIKE 40021 BUT u=716  $ Zirc pin
71604 LIKE 40022 BUT mat=2952 rho=-6.0124 vol=128.49 u=716 $ Slug 1
71605 LIKE 40023 BUT mat=2952 rho=-6.0124 vol=128.49 u=716 $ Slug 2
71606 LIKE 40024 BUT mat=2952 rho=-6.0124 vol=128.49 u=716 $ Slug 3
c
71701 LIKE 40019 BUT u=717  $ H2O
71702 LIKE 40020 BUT u=717  $ Cladding
71703 LIKE 40021 BUT u=717  $ Zirc pin
71704 LIKE 40022 BUT mat=9815 rho=-6.0124 vol=128.49 u=717 $ Slug 1
71705 LIKE 40023 BUT mat=9815 rho=-6.0124 vol=128.49 u=717 $ Slug 2
71706 LIKE 40024 BUT mat=9815 rho=-6.0124 vol=128.49 u=717 $ Slug 3
c
71801 LIKE 40019 BUT u=718  $ H2O
71802 LIKE 40020 BUT u=718  $ Cladding
71803 LIKE 40021 BUT u=718  $ Zirc pin
71804 LIKE 40022 BUT mat=2904 rho=-6.0124 vol=128.49 u=718 $ Slug 1
71805 LIKE 40023 BUT mat=2904 rho=-6.0124 vol=128.49 u=718 $ Slug 2
71806 LIKE 40024 BUT mat=2904 rho=-6.0124 vol=128.49 u=718 $ Slug 3
c
72001 LIKE 40019 BUT u=720  $ H2O
72002 LIKE 40020 BUT u=720  $ Cladding
72003 LIKE 40021 BUT u=720  $ Zirc pin
72004 LIKE 40022 BUT mat=2968 rho=-6.0124 vol=128.49 u=720 $ Slug 1
72005 LIKE 40023 BUT mat=2968 rho=-6.0124 vol=128.49 u=720 $ Slug 2
72006 LIKE 40024 BUT mat=2968 rho=-6.0124 vol=128.49 u=720 $ Slug 3
c
72101 LIKE 40019 BUT u=721  $ H2O
72102 LIKE 40020 BUT u=721  $ Cladding
72103 LIKE 40021 BUT u=721  $ Zirc pin
72104 LIKE 40022 BUT mat=2903 rho=-6.0124 vol=128.49 u=721 $ Slug 1
72105 LIKE 40023 BUT mat=2903 rho=-6.0124 vol=128.49 u=721 $ Slug 2
72106 LIKE 40024 BUT mat=2903 rho=-6.0124 vol=128.49 u=721 $ Slug 3
c
72201 LIKE 40019 BUT u=722  $ H2O
72202 LIKE 40020 BUT u=722  $ Cladding
```

```
72203 LIKE 40021 BUT u=722  $ Zirc pin
72204 LIKE 40022 BUT mat=2935 rho=-6.0124 vol=128.49 u=722 $ Slug 1
72205 LIKE 40023 BUT mat=2935 rho=-6.0124 vol=128.49 u=722 $ Slug 2
72206 LIKE 40024 BUT mat=2935 rho=-6.0124 vol=128.49 u=722 $ Slug 3
c
72301 LIKE 40019 BUT u=723  $ H2O
72302 LIKE 40020 BUT u=723  $ Cladding
72303 LIKE 40021 BUT u=723  $ Zirc pin
72304 LIKE 40022 BUT mat=2930 rho=-6.0124 vol=128.49 u=723 $ Slug 1
72305 LIKE 40023 BUT mat=2930 rho=-6.0124 vol=128.49 u=723 $ Slug 2
72306 LIKE 40024 BUT mat=2930 rho=-6.0124 vol=128.49 u=723 $ Slug 3
c
72401 LIKE 40019 BUT u=724  $ H2O
72402 LIKE 40020 BUT u=724  $ Cladding
72403 LIKE 40021 BUT u=724  $ Zirc pin
72404 LIKE 40022 BUT mat=2951 rho=-6.0124 vol=128.49 u=724 $ Slug 1
72405 LIKE 40023 BUT mat=2951 rho=-6.0124 vol=128.49 u=724 $ Slug 2
72406 LIKE 40024 BUT mat=2951 rho=-6.0124 vol=128.49 u=724 $ Slug 3
c
72601 LIKE 40019 BUT u=726  $ H2O
72602 LIKE 40020 BUT u=726  $ Cladding
72603 LIKE 40021 BUT u=726  $ Zirc pin
72604 LIKE 40022 BUT mat=9699 rho=-6.0124 vol=128.49 u=726 $ Slug 1
72605 LIKE 40023 BUT mat=9699 rho=-6.0124 vol=128.49 u=726 $ Slug 2
72606 LIKE 40024 BUT mat=9699 rho=-6.0124 vol=128.49 u=726 $ Slug 3
c
72701 LIKE 40019 BUT u=727  $ H2O
72702 LIKE 40020 BUT u=727  $ Cladding
72703 LIKE 40021 BUT u=727  $ Zirc pin
72704 LIKE 40022 BUT mat=2948 rho=-6.0124 vol=128.49 u=727 $ Slug 1
72705 LIKE 40023 BUT mat=2948 rho=-6.0124 vol=128.49 u=727 $ Slug 2
72706 LIKE 40024 BUT mat=2948 rho=-6.0124 vol=128.49 u=727 $ Slug 3
c
72801 LIKE 40019 BUT u=728  $ H2O
72802 LIKE 40020 BUT u=728  $ Cladding
72803 LIKE 40021 BUT u=728  $ Zirc pin
72804 LIKE 40022 BUT mat=2913 rho=-6.0124 vol=128.49 u=728 $ Slug 1
72805 LIKE 40023 BUT mat=2913 rho=-6.0124 vol=128.49 u=728 $ Slug 2
72806 LIKE 40024 BUT mat=2913 rho=-6.0124 vol=128.49 u=728 $ Slug 3
c
72901 LIKE 40019 BUT u=729  $ H2O
72902 LIKE 40020 BUT u=729  $ Cladding
72903 LIKE 40021 BUT u=729  $ Zirc pin
72904 LIKE 40022 BUT mat=2954 rho=-6.0124 vol=128.49 u=729 $ Slug 1
72905 LIKE 40023 BUT mat=2954 rho=-6.0124 vol=128.49 u=729 $ Slug 2
72906 LIKE 40024 BUT mat=2954 rho=-6.0124 vol=128.49 u=729 $ Slug 3
c
73001 LIKE 40019 BUT u=730  $ H2O
73002 LIKE 40020 BUT u=730  $ Cladding
73003 LIKE 40021 BUT u=730  $ Zirc pin
```

```
73004 LIKE 40022 BUT mat=9700 rho=-6.0124 vol=128.49 u=730 $ Slug 1
73005 LIKE 40023 BUT mat=9700 rho=-6.0124 vol=128.49 u=730 $ Slug 2
73006 LIKE 40024 BUT mat=9700 rho=-6.0124 vol=128.49 u=730 $ Slug 3
c
73201 LIKE 40019 BUT u=732  $ H2O
73202 LIKE 40020 BUT u=732  $ Cladding
73203 LIKE 40021 BUT u=732  $ Zirc pin
73204 LIKE 40022 BUT mat=1 rho=-6.0124 vol=128.49 u=732 $ Slug 1
73205 LIKE 40023 BUT mat=1 rho=-6.0124 vol=128.49 u=732 $ Slug 2
73206 LIKE 40024 BUT mat=1 rho=-6.0124 vol=128.49 u=732 $ Slug 3
c
73301 LIKE 40019 BUT u=733  $ H2O
73302 LIKE 40020 BUT u=733  $ Cladding
73303 LIKE 40021 BUT u=733  $ Zirc pin
73304 LIKE 40022 BUT mat=2918 rho=-6.0124 vol=128.49 u=733 $ Slug 1
73305 LIKE 40023 BUT mat=2918 rho=-6.0124 vol=128.49 u=733 $ Slug 2
73306 LIKE 40024 BUT mat=2918 rho=-6.0124 vol=128.49 u=733 $ Slug 3
c
73401 LIKE 40019 BUT u=734  $ H2O
73402 LIKE 40020 BUT u=734  $ Cladding
73403 LIKE 40021 BUT u=734  $ Zirc pin
73404 LIKE 40022 BUT mat=1 rho=-6.0124 vol=128.49 u=734 $ Slug 1
73405 LIKE 40023 BUT mat=1 rho=-6.0124 vol=128.49 u=734 $ Slug 2
73406 LIKE 40024 BUT mat=1 rho=-6.0124 vol=128.49 u=734 $ Slug 3
c
73501 LIKE 40019 BUT u=735  $ H2O
73502 LIKE 40020 BUT u=735  $ Cladding
73503 LIKE 40021 BUT u=735  $ Zirc pin
73504 LIKE 40022 BUT mat=9810 rho=-6.0124 vol=128.49 u=735 $ Slug 1
73505 LIKE 40023 BUT mat=9810 rho=-6.0124 vol=128.49 u=735 $ Slug 2
73506 LIKE 40024 BUT mat=9810 rho=-6.0124 vol=128.49 u=735 $ Slug 3
c
73601 LIKE 40019 BUT u=736  $ H2O
73602 LIKE 40020 BUT u=736  $ Cladding
73603 LIKE 40021 BUT u=736  $ Zirc pin
73604 LIKE 40022 BUT mat=9703 rho=-6.0124 vol=128.49 u=736 $ Slug 1
73605 LIKE 40023 BUT mat=9703 rho=-6.0124 vol=128.49 u=736 $ Slug 2
73606 LIKE 40024 BUT mat=9703 rho=-6.0124 vol=128.49 u=736 $ Slug 3
c --------------------------- END CELLS --------------------------------

c ************************* BEGIN SURFACES ******************************
c UNIVERSE BOUNDS
1     pz  80
2     pz -80
3     px   0
4     py   0
5     cz  90    $ Reactor Pool
6     cz  53.34 $ Reflector outer radius (42" OD)
c HEXAGONAL LATTICE CELL GEOMETRY, pitch (1.714 in.)
101       px  2.17678
```

```
102       px -2.17678
103    1  py  2.17678
104    1  py -2.17678
105    2  px  2.17678
106    2  px -2.17678
c HEXAGONAL SHROUD
201     rhp 0 0 -100 0 0 200 27.78125 0 0
202     rhp 0 0 -100 0 0 200 27.305 0 0
203   1 rhp 0 0 -100 0 0 200 26.43188 0 0
204   1 rhp 0 0 -100 0 0 200 25.95563 0 0
c Cylindrical Surfaces
301  cz  0.3175  $ Fuel inner radius/Zr fill rod (0.25 in. ID)
302  cz  0.86995 $ Rabbit ID (0.685 in. ID)
303  cz  1.11125 $ Rabbit OD (7/8 in. OD)
304  cz  1.21285 $ Cadmium in Rabbit OD (0.02 in thick double wrapped)
305  cz  1.245   $ Source cavity OD (0.981 in., per Maintenance Manual)
306  cz  1.4224  $ Cadmium Rabbit ID (1.12 in)
307  cz  1.50749 $ Transient Rod - OD of absorber (1.187 in. ID)
308  cz  1.51638 $ Transient Rod - clad inner surface (0.028 in. wall)
309  cz  1.5875  $ Transient Rod - clad outer surface (1.25 in. OD)
310  cz  1.5875  $ Cadmium Rabbit OD (1.25 in)
311  cz  1.651   $ FFCR - OD of absorber (1.300 in. ID)
312  cz  1.6637  $ FFCR - clad inner surface (0.02 in. wall, 1.31 in. ID)
313  cz  1.69    $ Central Thimble ID (1.33 in. ID)
314  cz  1.7145  $ FFCR - clad outer surface (1.35 in. OD)
315  cz  1.8161  $ Fuel graphite reflector radius (1.43 in. OD)
316  cz  1.82245 $ Fuel Meat outer radius (1.435 in. OD)
317  cz  1.87325 $ Fuel Cladding outer radius (1.475 in. OD)
318  cz  1.905   $ Central Thimble OD (1.5 in. OD)
319  cz  1.91135 $ Grid Plate penetrations (1.505 in. top)
320  cz 36.35375 $ RSR cavity outer ring (28 5/8" OD)
321  c/z 0 -2.51353 0.866950 $ Universe 2 Inner Al Inside Radius
322  c/z 0 -2.51353 1.029510 $ Universe 2 Inner Al Outside Radius
323  c/z 0 -2.51353 1.188260 $ Universe 2 Cd Radius
324  c/z 0 -2.51353 1.350820 $ Universe 2 Cd-B Al Radius
325  c/z 0 -2.51353 1.827070 $ Universe 2 B Radius
326  c/z 0 -2.51353 1.989630 $ Universe 2 B-U Al Radius
327  c/z 0 -2.51353 2.218690 $ Universe 2 Uranium Radius
328  c/z 0 -2.51353 2.381250 $ Universe 2 Outer Aluminum Radius
331  c/z 2.17678 1.25677 0.866950 $ Universe 12 Inner Al Inside Radius
332  c/z 2.17678 1.25677 1.029510 $ Universe 12 Inner Al Outside Radius
333  c/z 2.17678 1.25677 1.188260 $ Universe 12 Cd Radius
334  c/z 2.17678 1.25677 1.350820 $ Universe 12 Cd-B Al Radius
335  c/z 2.17678 1.25677 1.827070 $ Universe 12 B Radius
336  c/z 2.17678 1.25677 1.989630 $ Universe 12 B-U Al Radius
337  c/z 2.17678 1.25677 2.218690 $ Universe 12 Uranium Radius
338  c/z 2.17678 1.25677 2.381250 $ Universe 12 Outer Aluminum Radius
341  c/z -2.17678 1.25677 0.866950 $ Universe 13 Inner Al Inside Radius
342  c/z -2.17678 1.25677 1.029510 $ Universe 13 Inner Al Outside Radius
343  c/z -2.17678 1.25677 1.188260 $ Universe 13 Cd Radius
```

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344  c/z -2.17678 1.25677 1.350820 $ Universe 13 Cd-B Al Radius
345  c/z -2.17678 1.25677 1.827070 $ Universe 13 B Radius
346  c/z -2.17678 1.25677 1.989630 $ Universe 13 B-U Al Radius
347  c/z -2.17678 1.25677 2.218690 $ Universe 13 Uranium Radius
348  c/z -2.17678 1.25677 2.381250 $ Universe 13 Outer Aluminum Radius
c Core Axial Surfaces
401   k/z 0 0 34.2792 0.25 -1  $ upper cone
402   pz  32.385  $ Upper grid plate, top (0.62 in. thick, 12.75 in. from midplane)
403   pz  30.8102 $ Upper grid plate, bottom (and top of reflector can)
404   pz  26.924  $ Bottom of top end fitting (0.5 in. air gap = 1.27 cm)
405   pz  25.654  $ Top of upper graphite slug (2.6 in. = 6.604 cm)
406   pz  19.05   $ Upper graphite slug bottom/upper fuel slug top
407   pz   6.35   $ Fuel upper slug bottom/middle slug top
408   pz   3.81   $ Top of source cavity
409   pz   3.334  $ Bottom of rotating rack (27.4 cm deep)
410   pz  -3.81   $ Bottom of source cavity (3 in. cavity)
411   pz  -6.35   $ Fuel middle slug bottom/lower slug top
412   pz -18.7182 $ Top of Rabbit shock absorber
413   pz -19.05   $ Fuel Bottom
414   pz -19.13   $ Moly disk/top of lower graphite slug (1/32 in. = 0.08 cm)
415   pz -21.2582 $ Top of Cd Rabbit discs
416   pz -21.309  $ Bottom of Cd Rabbit discs (0.0508 cm thick)
417   pz -23.849  $ Rabbit terminus connecting tube (1.25" OD portion)
418   pz -27.94   $ Bottom of reflector can (8.25 in. from bp center at -6.985 cm)
419   pz -28.0215 $ Rabbit terminus lower end (1.45" OD, 5.2275" long)
420   pz -28.528  $ Bottom of lower graphite/plug top (3.7 in. = 9.398 cm)
421   pz -31.979  $ Bottom of source holder (0.5 in. above lower grid plate)
422   pz -33.1724 $ Lower grid plate, top (1.25 in. thick, 13.06 in. from midplane)
423   pz -36.3474 $ Lower grid plate, bottom
424   k/z 0 0 -36.1489 0.25 1  $ lower cone
425   RCC 0 -2.51353 0 0 0 2.54 0.43        $ Tally sample for universe 2
426   RCC 2.17678 1.25677 0 0 0 2.54 0.43   $ Tally sample for universe 12
427   RCC -2.17678 1.25677 0 0 0 2.54 0.43  $ Tally sample for universe 13
c Beam Port Surfaces
501   c/x 35.2425 -6.985 7.70255 $ Tangential thru beam port bp1/5
502   c/x 35.2425 -6.985 8.41375 $ Tangential thru beam port bp1/5
503   10  cy 7.70255 $ Tangential beam port, bp2
504   10  cy 8.41375 $ Tangential beam port, bp2
505    3  py -12.621 $ Tangential beam port, bp2
506   c/y 0 -6.985 7.70255 $ Radial penetrating beam port, bp3
507   c/y 0 -6.985 8.41375 $ Radial penetrating beam port, bp3
508   11  cy 7.70255 $ Radial beam port, bp4
509   11  cy 8.41375 $ Radial beam port, bp4
c Lazy Susan (1.0" OD tubes, 0.058" wall thickness, 13.156" to tube center)
1301  c/z   0            33.41624     1.12268 $ lazy susan rack position 01
1302  c/z   5.227451628  33.00483063  1.12268 $ lazy susan rack position 02
1303  c/z  10.32618605   31.7807328   1.12268 $ lazy susan rack position 03
1304  c/z  15.1706555    29.77408785  1.12268 $ lazy susan rack position 04
1305  c/z  19.64157306   27.03430605  1.12268 $ lazy susan rack position 05
1306  c/z  23.62884991   23.62884991  1.12268 $ lazy susan rack position 06
```

```
1307  c/z  27.03430605   19.64157306  1.12268 $ lazy susan rack position 07
1308  c/z  29.77408785   15.1706555   1.12268 $ lazy susan rack position 08
1309  c/z  31.7807328    10.32618605  1.12268 $ lazy susan rack position 09
1310  c/z  33.00483063    5.227451628 1.12268 $ lazy susan rack position 10
1311  c/z  33.41624       0           1.12268 $ lazy susan rack position 11
1312  c/z  33.00483063   -5.227451628 1.12268 $ lazy susan rack position 12
1313  c/z  31.7807328   -10.32618605  1.12268 $ lazy susan rack position 13
1314  c/z  29.77408785  -15.1706555   1.12268 $ lazy susan rack position 14
1315  c/z  27.03430605  -19.64157306  1.12268 $ lazy susan rack position 15
1316  c/z  23.62884991  -23.62884991  1.12268 $ lazy susan rack position 16
1317  c/z  19.64157306  -27.03430605  1.12268 $ lazy susan rack position 17
1318  c/z  15.1706555   -29.77408785  1.12268 $ lazy susan rack position 18
1319  c/z  10.32618605  -31.7807328   1.12268 $ lazy susan rack position 19
1320  c/z   5.227451628 -33.00483063  1.12268 $ lazy susan rack position 20
1321  c/z   0           -33.41624     1.12268 $ lazy susan rack position 21
1322  c/z  -5.227451628 -33.00483063  1.12268 $ lazy susan rack position 22
1323  c/z -10.32618605  -31.7807328   1.12268 $ lazy susan rack position 23
1324  c/z -15.1706555   -29.77408785  1.12268 $ lazy susan rack position 24
1325  c/z -19.64157306  -27.03430605  1.12268 $ lazy susan rack position 25
1326  c/z -23.62884991  -23.62884991  1.12268 $ lazy susan rack position 26
1327  c/z -27.03430605  -19.64157306  1.12268 $ lazy susan rack position 27
1328  c/z -29.77408785  -15.1706555   1.12268 $ lazy susan rack position 28
1329  c/z -31.7807328   -10.32618605  1.12268 $ lazy susan rack position 29
1330  c/z -33.00483063   -5.227451628 1.12268 $ lazy susan rack position 30
1331  c/z -33.41624       0           1.12268 $ lazy susan rack position 31
1332  c/z -33.00483063    5.227451628 1.12268 $ lazy susan rack position 32
1333  c/z -31.7807328    10.32618605  1.12268 $ lazy susan rack position 33
1334  c/z -29.77408785   15.1706555   1.12268 $ lazy susan rack position 34
1335  c/z -27.03430605   19.64157306  1.12268 $ lazy susan rack position 35
1336  c/z -23.62884991   23.62884991  1.12268 $ lazy susan rack position 36
1337  c/z -19.64157306   27.03430605  1.12268 $ lazy susan rack position 37
1338  c/z -15.1706555    29.77408785  1.12268 $ lazy susan rack position 38
1339  c/z -10.32618605   31.7807328   1.12268 $ lazy susan rack position 39
1340  c/z  -5.227451628  33.00483063  1.12268 $ lazy susan rack position 40
c Lazy Susan Sample Tube Cladding (1" diameter holes and 0.058" wall thickness)
1341  c/z   0            33.41624     1.27 $ lazy susan rack position 01
1342  c/z   5.227451628  33.00483063  1.27 $ lazy susan rack position 02
1343  c/z  10.32618605   31.7807328   1.27 $ lazy susan rack position 03
1344  c/z  15.1706555    29.77408785  1.27 $ lazy susan rack position 04
1345  c/z  19.64157306   27.03430605  1.27 $ lazy susan rack position 05
1346  c/z  23.62884991   23.62884991  1.27 $ lazy susan rack position 06
1347  c/z  27.03430605   19.64157306  1.27 $ lazy susan rack position 07
1348  c/z  29.77408785   15.1706555   1.27 $ lazy susan rack position 08
1349  c/z  31.7807328    10.32618605  1.27 $ lazy susan rack position 09
1350  c/z  33.00483063    5.227451628 1.27 $ lazy susan rack position 10
1351  c/z  33.41624       0           1.27 $ lazy susan rack position 11
1352  c/z  33.00483063   -5.227451628 1.27 $ lazy susan rack position 12
1353  c/z  31.7807328   -10.32618605  1.27 $ lazy susan rack position 13
1354  c/z  29.77408785  -15.1706555   1.27 $ lazy susan rack position 14
1355  c/z  27.03430605  -19.64157306  1.27 $ lazy susan rack position 15
```

```
1356  c/z  23.62884991  -23.62884991  1.27 $ lazy susan rack position 16
1357  c/z  19.64157306  -27.03430605  1.27 $ lazy susan rack position 17
1358  c/z  15.1706555   -29.77408785  1.27 $ lazy susan rack position 18
1359  c/z  10.32618605  -31.7807328   1.27 $ lazy susan rack position 19
1360  c/z   5.227451628 -33.00483063  1.27 $ lazy susan rack position 20
1361  c/z   0           -33.41624     1.27 $ lazy susan rack position 21
1362  c/z  -5.227451628 -33.00483063  1.27 $ lazy susan rack position 22
1363  c/z -10.32618605  -31.7807328   1.27 $ lazy susan rack position 23
1364  c/z -15.1706555   -29.77408785  1.27 $ lazy susan rack position 24
1365  c/z -19.64157306  -27.03430605  1.27 $ lazy susan rack position 25
1366  c/z -23.62884991  -23.62884991  1.27 $ lazy susan rack position 26
1367  c/z -27.03430605  -19.64157306  1.27 $ lazy susan rack position 27
1368  c/z -29.77408785  -15.1706555   1.27 $ lazy susan rack position 28
1369  c/z -31.7807328   -10.32618605  1.27 $ lazy susan rack position 29
1370  c/z -33.00483063   -5.227451628 1.27 $ lazy susan rack position 30
1371  c/z -33.41624       0           1.27 $ lazy susan rack position 31
1372  c/z -33.00483063    5.227451628 1.27 $ lazy susan rack position 32
1373  c/z -31.7807328    10.32618605  1.27 $ lazy susan rack position 33
1374  c/z -29.77408785   15.1706555   1.27 $ lazy susan rack position 34
1375  c/z -27.03430605   19.64157306  1.27 $ lazy susan rack position 35
1376  c/z -23.62884991   23.62884991  1.27 $ lazy susan rack position 36
1377  c/z -19.64157306   27.03430605  1.27 $ lazy susan rack position 37
1378  c/z -15.1706555    29.77408785  1.27 $ lazy susan rack position 38
1379  c/z -10.32618605   31.7807328   1.27 $ lazy susan rack position 39
1380  c/z  -5.227451628  33.00483063  1.27 $ lazy susan rack position 40
c Lazy Susan Axial Planes from top to bottom
1381  pz 13.334 $ 10 cm above the bottom of the lazy susan
1382  pz 12.334 $ 9 cm above the bottom of the lazy susan
1383  pz 11.334 $ 8 cm above the bottom of the lazy susan
1384  pz 10.334 $ 7 cm above the bottom of the lazy susan
1385  pz  9.334 $ 6 cm above the bottom of the lazy susan
1386  pz  8.334 $ 5 cm above the bottom of the lazy susan
1387  pz  7.334 $ 4 cm above the bottom of the lazy susan
1388  pz  6.334 $ 3 cm above the bottom of the lazy susan
1389  pz  5.334 $ 2 cm above the bottom of the lazy susan
1390  pz  4.334 $ 1 cm above the bottom of the lazy susan
c Control element surfaces
c Transient Rod (950 units, 100.0% withdrawn)
601  pz  60.96  $ Control element - element plug, end (0.5 in. plug)
602  pz  59.69  $ Control element - magneform plug, upper (1 in. magneform)
603  pz  57.15  $ Control element - top of absorber (15 in. absorber)
604  pz  19.05  $ Control element - bottom of absorber
605  pz  16.51  $ Control element - magneform plug, lower (1 in. double magneform)
606  pz  -33.655  $ Control element - air follower section (19.75 in. void)
607  pz  -34.925  $ Control element - element plug, end (0.5 in. plug)
c
c Regulating Rod (950 units, 100.0% withdrawn)
701  pz  71.438  $ Control element - element plug, end (1.5 in. plug)
702  pz  67.628  $ Control element - void gap (3.5 in. gap)
703  pz  58.738  $ Control element - magneform plug, upper (0.5 in. magneform)
```

```
704  pz  57.468  $ Control element - void gap (1/8 in. gap)
705  pz  57.15  $ Control element - top of absorber (15 in. absorber)
706  pz  19.05  $ Control element - bottom of absorber
707  pz  17.78  $ Control element - magneform plug, lower (0.5 in. magneform)
708  pz  17.145  $ Control element - void gap/top of fuel (0.25 in. gap)
709  pz  4.445  $ Bottom of top fuel slug
710  pz  -8.255  $ Bottom of middle fuel slug
711  pz  -20.955  $ Bottom of bottom fuel slug
712  pz  -23.495  $ Control element - magneform (1 in. double magneform)
713  pz  -37.148  $ Control element - void gap (5 3/8 in. gap)
714  pz  -38.418  $ Control element - element plug, end (0.5 in. plug)
c
c Shim 1 Rod (950 units, 100.0% withdrawn)
801  pz  71.438  $ Control element - element plug, end (1.5 in. plug)
802  pz  67.628  $ Control element - void gap (3.5 in. gap)
803  pz  58.738  $ Control element - magneform plug, upper (0.5 in. magneform)
804  pz  57.468  $ Control element - void gap (1/8 in. gap)
805  pz  57.15  $ Control element - top of absorber (15 in. absorber)
806  pz  19.05  $ Control element - bottom of absorber
807  pz  17.78  $ Control element - magneform plug, lower (0.5 in. magneform)
808  pz  17.145  $ Control element - void gap/top of fuel (0.25 in. gap)
809  pz  4.445  $ Bottom of top fuel slug
810  pz  -8.255  $ Bottom of middle fuel slug
811  pz  -20.955  $ Bottom of bottom fuel slug
812  pz  -23.495  $ Control element - magneform (1 in. double magneform)
813  pz  -37.148  $ Control element - void gap (5 3/8 in. gap)
814  pz  -38.418  $ Control element - element plug, end (0.5 in. plug)
c
c Shim 2 Rod (950 units, 100.0% withdrawn)
901  pz  71.438  $ Control element - element plug, end (1.5 in. plug)
902  pz  67.628  $ Control element - void gap (3.5 in. gap)
903  pz  58.738  $ Control element - magneform plug, upper (0.5 in. magneform)
904  pz  57.468  $ Control element - void gap (1/8 in. gap)
905  pz  57.15  $ Control element - top of absorber (15 in. absorber)
906  pz  19.05  $ Control element - bottom of absorber
907  pz  17.78  $ Control element - magneform plug, lower (0.5 in. magneform)
908  pz  17.145  $ Control element - void gap/top of fuel (0.25 in. gap)
909  pz  4.445  $ Bottom of top fuel slug
910  pz  -8.255  $ Bottom of middle fuel slug
911  pz  -20.955  $ Bottom of bottom fuel slug
912  pz  -23.495  $ Control element - magneform (1 in. double magneform)
913  pz  -37.148  $ Control element - void gap (5 3/8 in. gap)
914  pz  -38.418  $ Control element - element plug, end (0.5 in. plug)
c ------------------------ END SURFACES -----------------------------

c ************************ BEGIN MATERIAL CARDS ********************
c For coordinate transforms Q1 Q2 Q3 B1 B2 B3 B4 B5 B6 B7 B8 B9 M
c *tr means Bi are angles in degrees rather than cosines of angles
c Q1-Q3 = displacement vector of the transformation
c B1-B9 = rotation matrix of the transformation
```

```
c B1=X,X' B2=Y,X' B3=Z,X' B4=X,Y' B5=Y,Y' B6=Z,Y' B7=X,Z' B8=Y,Z' B9=Z,Z'
c M = 1 means displacement vector is in origin of aux coordinate system
*tr1 0 0 0 30 120 90 60 30 90 j j j
*tr2 0 0 0 120 30 90 30 60 90 j j j
*tr3 0 0 0 20 100 90 125 20 90 j j j
*tr10 35.255 6.222 -6.985 150 120 90 60 150 90 j j j
*tr11 -22.871 -13.216 -6.985 75 120 90 60 75 90 j j j
c Note: positive number means atom fraction, negative number means mass fraction
m1    1001.80c   -0.014355  $ UZrH fuel, 5.8 g/cc
      24000 -0.013573  25055.80c -0.0014287 26000 -0.049647
      28000 -0.0067863 92235.80c  -0.0152 92238.80c -0.061568
      40090.80c -0.43706 40091.80c -0.0942  40092.80c -0.14253
      40094.80c -0.14136 40096.80c -0.02228
mt1   h-zr.20t zr-h.30t
c Water that is not heated (rho = 1.0 g/cc)
m2    1001.80c 0.6667 8016.80c 0.3333 $ h2o (always .80c)
mt2   lwtr.20t $ h2o salphabeta card (always .20t)
c Water that is heated
m22   1001.80c 0.6667 8016.80c 0.3333 $ (possibly heated)
mt22  lwtr.21t $ h2o salphabeta card (possibly heated)
c Zirconium $ Zirc  Filler, rho = 6.5 g/cc
m3    40090.81c .5145 40091.81c .1122 40092.81c .1715 $ zirconium (possibly heated)
      40094.81c .1738 40096.81c .0280
c Stainless Steel rho =  7.9 g/cc
m4    6000.81c 0.00031519 24050.81c 7.8200E-4 24052.81c 1.4501E-2 $ SS 304 Clad
(possibly heated)
      24053.81c 1.6130E-3 24054.81c 3.9400E-4 26054.81c 3.5540E-3
      26056.81c 5.5110E-2 26057.81c 1.2570E-3 26058.81c 1.6600E-4
      28058.81c 5.5580E-3 28060.81c 2.0700E-3 28061.81c 8.8500E-5
      28062.81c 2.7800E-4 28064.81c 6.8500E-5
c Graphite rho = 1.6 g/cc
m5    6000.80c  1 $ Graphite, 1.6 g/cc (always .80c)
mt5   grph.20t
c Graphite rho = 1.6 g/cc
m55    6000.81c  1 $ Graphite, 1.6 g/cc (possibly heated)
mt55   grph.23t
c Aluminum rho = 2.699 g/cc
m6     5010.80c 2.3945E-7 12024.80c 5.3511E-4 12025.80c 6.5030E-5  $ 6061-T6
aluminum (always .80c)
      12026.80c 6.8851E-5 13027.80c 5.9015E-2 14028.80c 3.2153E-4
      14029.80c 1.5771E-5 14030.80c 1.0062E-5 24050.80c 2.6872E-6
      24052.80c 4.9830E-5 24053.80c 5.5435E-6 24054.80c 1.3544E-6
      29063.80c 5.0017E-5 29065.80c 2.1628E-5
m66     5010.81c 2.3945E-7 12024.81c 5.3511E-4 12025.81c 6.5030E-5  $ 6061-T6
aluminum (possibly heated)
      12026.81c 6.8851E-5 13027.81c 5.9015E-2 14028.81c 3.2153E-4
      14029.81c 1.5771E-5 14030.81c 1.0062E-5 24050.81c 2.6872E-6
      24052.81c 4.9830E-5 24053.81c 5.5435E-6 24054.81c 1.3544E-6
      29063.81c 5.0017E-5 29065.81c 2.1628E-5
c Air  rho = 0.001205
```

```
m8    7014.80c 0.79 8016.80c 0.21 $ air (always .80c)
c Boron Carbide rho = 2.48 (possibly heated)
m9    5010.81c  0.1592 5011.81c  0.6408 6000.81c  0.2
c Molybdenum rho = 10.3 (possibly heated)
m10   42092.81c .1477  42094.81c .0923  42095.81c .159
      42096.81c .1668  42097.81c .0956  42098.81c .2419 42100.81c .0967  $ 9.33 g/cc
c Cadmium rho = 8.65 (possibly heated)
m20   48106.81c 0.0125 48108.81c 0.0089 48110.81c 0.1249 48111.81c 0.1280
      48112.81c 0.2413 48113.81c 0.1222 48114.81c 0.2873 48116.81c 0.0749
c -------------------  END DATA ----------------
m2899
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       92235.81c 2.286E-03
       92236.81c 4.817E-05
       92237.81c 1.606E-08
       92238.81c 1.023E-02
       92239.81c 2.683E-09
       93237.81c 2.020E-07
       93238.81c 1.235E-10
       93239.81c 3.876E-07
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       94239.81c 2.229E-05
       94240.81c 1.196E-06
       94241.81c 8.119E-08
       94242.81c 1.641E-09
       95241.81c 4.907E-10
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       34079.81c 9.657E-08
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       34082.81c 7.023E-07
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      5.15225 -0.79869 -10
      5.47543 -1.12187 0
      5.47543 -1.12187 10
      5.47543 -1.12187 -10
      2.55986 -4.15244 0 $ B2 source
      2.55986 -4.15244 10
      2.55986 -4.15244 -10
      2.97547 -4.56805 0
      2.97547 -4.56805 10
      2.97547 -4.56805 -10
      3.29865 -4.89123 0
      3.29865 -4.89123 10
      3.29865 -4.89123 -10
      -2.55986 -4.15244 0 $ B3 source
      -2.55986 -4.15244 10
```

```
-2.55986 -4.15244 -10
-2.97547 -4.56805 0
-2.97547 -4.56805 10
-2.97547 -4.56805 -10
-3.29865 -4.89123 0
-3.29865 -4.89123 10
-3.29865 -4.89123 -10
-4.73664 -0.38308 0 $ B4 source
-4.73664 -0.38308 10
-4.73664 -0.38308 -10
-5.15225 -0.79869 0
-5.15225 -0.79869 10
-5.15225 -0.79869 -10
-5.47543 -1.12187 0
-5.47543 -1.12187 10
-5.47543 -1.12187 -10
-2.55986 4.15244 0 $ B5 source
-2.55986 4.15244 10
-2.55986 4.15244 -10
-2.97547 4.56805 0
-2.97547 4.56805 10
-2.97547 4.56805 -10
-3.29865 4.89123 0
-3.29865 4.89123 10
-3.29865 4.89123 -10
2.55986 4.15244 0 $ B6 source
2.55986 4.15244 10
2.55986 4.15244 -10
2.97547 4.56805 0
2.97547 4.56805 10
2.97547 4.56805 -10
3.29865 4.89123 0
3.29865 4.89123 10
3.29865 4.89123 -10
6.91342 -4.198444 0 $ C2 source
6.91342 -4.198444 10
6.91342 -4.198444 -10
7.32903 -4.614054 0
7.32903 -4.614054 10
7.32903 -4.614054 -10
7.65221 -4.937234 0
7.65221 -4.937234 10
7.65221 -4.937234 -10
4.73664 -7.92434 0 $ C3 source
4.73664 -7.92434 10
4.73664 -7.92434 -10
5.15225 -8.33995 0
5.15225 -8.33995 10
5.15225 -8.33995 -10
5.47543 -8.66313 0
```

```
5.47543 -8.66313 10
5.47543 -8.66313 -10
-4.73664 -7.92434 0 $ C5 source
-4.73664 -7.92434 10
-4.73664 -7.92434 -10
-5.15225 -8.33995 0
-5.15225 -8.33995 10
-5.15225 -8.33995 -10
-5.47543 -8.66313 0
-5.47543 -8.66313 10
-5.47543 -8.66313 -10
-6.91342 -4.198444 0 $ C6 source
-6.91342 -4.198444 10
-6.91342 -4.198444 -10
-7.32903 -4.614054 0
-7.32903 -4.614054 10
-7.32903 -4.614054 -10
-7.65221 -4.937234 0
-7.65221 -4.937234 10
-7.65221 -4.937234 -10
-9.0902 -0.38308 0 $ C7 source (Reg Rod)
-9.0902 -0.38308 10
-9.0902 -0.38308 -10
-9.50581 -0.79869 0
-9.50581 -0.79869 10
-9.50581 -0.79869 -10
-9.82899 -1.12187 0
-9.82899 -1.12187 10
-9.82899 -1.12187 -10
-6.91342 4.198444 0 $ C8 source
-6.91342 4.198444 10
-6.91342 4.198444 -10
-7.32903 4.614054 0
-7.32903 4.614054 10
-7.32903 4.614054 -10
-7.65221 4.937234 0
-7.65221 4.937234 10
-7.65221 4.937234 -10
-4.73664 7.92434 0 $ C9 source
-4.73664 7.92434 10
-4.73664 7.92434 -10
-5.15225 8.33995 0
-5.15225 8.33995 10
-5.15225 8.33995 -10
-5.47543 8.66313 0
-5.47543 8.66313 10
-5.47543 8.66313 -10
-0.38308 7.92434 0 $ C10 source
-0.38308 7.92434 10
-0.38308 7.92434 -10
```

```
-0.79869 8.33995 0
-0.79869 8.33995 10
-0.79869 8.33995 -10
-1.12187 8.66313 0
-1.12187 8.66313 10
-1.12187 8.66313 -10
4.73664 7.92434 0 $ C11 source
4.73664 7.92434 10
4.73664 7.92434 -10
5.15225 8.33995 0
5.15225 8.33995 10
5.15225 8.33995 -10
5.47543 8.66313 0
5.47543 8.66313 10
5.47543 8.66313 -10
6.91342 4.198444 0 $ C12 source
6.91342 4.198444 10
6.91342 4.198444 -10
7.32903 4.614054 0
7.32903 4.614054 10
7.32903 4.614054 -10
7.65221 4.937234 0
7.65221 4.937234 10
7.65221 4.937234 -10
13.44376 -0.38308 0 $ D1 source
13.44376 -0.38308 10
13.44376 -0.38308 -10
13.85937 -0.79869 0
13.85937 -0.79869 10
13.85937 -0.79869 -10
14.18255 -1.12187 0
14.18255 -1.12187 10
14.18255 -1.12187 -10
11.26698 -4.15244 0 $ D2 source
11.26698 -4.15244 10
11.26698 -4.15244 -10
11.68259 -4.56805 0
11.68259 -4.56805 10
11.68259 -4.56805 -10
12.00577 -4.89123 0
12.00577 -4.89123 10
12.00577 -4.89123 -10
9.0902 -7.92434 0 $ D3 source
9.0902 -7.92434 10
9.0902 -7.92434 -10
9.50581 -8.33995 0
9.50581 -8.33995 10
9.50581 -8.33995 -10
9.82899 -8.66313 0
9.82899 -8.66313 10
```

```
9.82899 -8.66313 -10
6.91342 -11.6937 0 $ D4 source
6.91342 -11.6937 10
6.91342 -11.6937 -10
7.32903 -12.10931 0
7.32903 -12.10931 10
7.32903 -12.10931 -10
7.65221 -12.43249 0
7.65221 -12.43249 10
7.65221 -12.43249 -10
2.55986 -11.6937 0 $ D5 source
2.55986 -11.6937 10
2.55986 -11.6937 -10
2.97547 -12.10931 0
2.97547 -12.10931 10
2.97547 -12.10931 -10
3.29865 -12.43249 0
3.29865 -12.43249 10
3.29865 -12.43249 -10
-2.55986 -11.6937 0 $ D6 source (Shim 1)
-2.55986 -11.6937 10
-2.55986 -11.6937 -10
-2.97547 -12.10931 0
-2.97547 -12.10931 10
-2.97547 -12.10931 -10
-3.29865 -12.43249 0
-3.29865 -12.43249 10
-3.29865 -12.43249 -10
-6.91342 -11.6937 0 $ D7 source
-6.91342 -11.6937 10
-6.91342 -11.6937 -10
-7.32903 -12.10931 0
-7.32903 -12.10931 10
-7.32903 -12.10931 -10
-7.65221 -12.43249 0
-7.65221 -12.43249 10
-7.65221 -12.43249 -10
-9.0902 -7.92434 0 $ D8 source
-9.0902 -7.92434 10
-9.0902 -7.92434 -10
-9.50581 -8.33995 0
-9.50581 -8.33995 10
-9.50581 -8.33995 -10
-9.82899 -8.66313 0
-9.82899 -8.66313 10
-9.82899 -8.66313 -10
-11.26698 -4.15244 0 $ D9 source
-11.26698 -4.15244 10
-11.26698 -4.15244 -10
-11.68259 -4.56805 0
```

```
-11.68259 -4.56805 10
-11.68259 -4.56805 -10
-12.00577 -4.89123 0
-12.00577 -4.89123 10
-12.00577 -4.89123 -10
-13.44376 -0.38308 0 $ D10 source
-13.44376 -0.38308 10
-13.44376 -0.38308 -10
-13.85937 -0.79869 0
-13.85937 -0.79869 10
-13.85937 -0.79869 -10
-14.18255 -1.12187 0
-14.18255 -1.12187 10
-14.18255 -1.12187 -10
-11.26698 4.15244 0 $ D11 source
-11.26698 4.15244 10
-11.26698 4.15244 -10
-11.68259 4.56805 0
-11.68259 4.56805 10
-11.68259 4.56805 -10
-12.00577 4.89123 0
-12.00577 4.89123 10
-12.00577 4.89123 -10
-9.0902 7.92434 0 $ D12 source
-9.0902 7.92434 10
-9.0902 7.92434 -10
-9.50581 8.33995 0
-9.50581 8.33995 10
-9.50581 8.33995 -10
-9.82899 8.66313 0
-9.82899 8.66313 10
-9.82899 8.66313 -10
-6.91342 11.6937 0 $ D13 source
-6.91342 11.6937 10
-6.91342 11.6937 -10
-7.32903 12.10931 0
-7.32903 12.10931 10
-7.32903 12.10931 -10
-7.65221 12.43249 0
-7.65221 12.43249 10
-7.65221 12.43249 -10
-2.55986 11.6937 0 $ D14 source (Shim 2 Rod)
-2.55986 11.6937 10
-2.55986 11.6937 -10
-2.97547 12.10931 0
-2.97547 12.10931 10
-2.97547 12.10931 -10
-3.29865 12.43249 0
-3.29865 12.43249 10
-3.29865 12.43249 -10
```

```
2.55986 11.6937 0 $ D15 source
2.55986 11.6937 10
2.55986 11.6937 -10
2.97547 12.10931 0
2.97547 12.10931 10
2.97547 12.10931 -10
3.29865 12.43249 0
3.29865 12.43249 10
3.29865 12.43249 -10
6.91342 11.6937 0 $ D16 source
6.91342 11.6937 10
6.91342 11.6937 -10
7.32903 12.10931 0
7.32903 12.10931 10
7.32903 12.10931 -10
7.65221 12.43249 0
7.65221 12.43249 10
7.65221 12.43249 -10
9.0902 7.92434 0 $ D17 source
9.0902 7.92434 10
9.0902 7.92434 -10
9.50581 8.33995 0
9.50581 8.33995 10
9.50581 8.33995 -10
9.82899 8.66313 0
9.82899 8.66313 10
9.82899 8.66313 -10
11.26698 4.15244 0 $ D18 source
11.26698 4.15244 10
11.26698 4.15244 -10
11.68259 4.56805 0
11.68259 4.56805 10
11.68259 4.56805 -10
12.00577 4.89123 0
12.00577 4.89123 10
12.00577 4.89123 -10
17.79732 -0.38308 0 $ E1 source
17.79732 -0.38308 10
17.79732 -0.38308 -10
18.21293 -0.79869 0
18.21293 -0.79869 10
18.21293 -0.79869 -10
18.53611 -1.12187 0
18.53611 -1.12187 10
18.53611 -1.12187 -10
15.62054 -4.15244 0 $ E2 source
15.62054 -4.15244 10
15.62054 -4.15244 -10
16.03615 -4.56805 0
16.03615 -4.56805 10
```

```
16.03615 -4.56805 -10
16.35933 -4.89123 0
16.35933 -4.89123 10
16.35933 -4.89123 -10
13.44376 -7.92434 0 $ E3 source
13.44376 -7.92434 10
13.44376 -7.92434 -10
13.85937 -8.33995 0
13.85937 -8.33995 10
13.85937 -8.33995 -10
14.18255 -8.66313 0
14.18255 -8.66313 10
14.18255 -8.66313 -10
11.6937 -11.26698 0 $ E4 source
11.6937 -11.26698 10
11.6937 -11.26698 -10
12.10931 -11.68259 0
12.10931 -11.68259 10
12.10931 -11.68259 -10
12.43249 -12.00577 0
12.43249 -12.00577 10
12.43249 -12.00577 -10
9.0902 -15.4656 0 $ E5 source
9.0902 -15.4656 10
9.0902 -15.4656 -10
9.50581 -15.88121 0
9.50581 -15.88121 10
9.50581 -15.88121 -10
9.82899 -16.20439 0
9.82899 -16.20439 10
9.82899 -16.20439 -10
4.73664 -15.4656 0 $ E6 source
4.73664 -15.4656 10
4.73664 -15.4656 -10
5.15225 -15.88121 0
5.15225 -15.88121 10
5.15225 -15.88121 -10
5.47543 -16.20439 0
5.47543 -16.20439 10
5.47543 -16.20439 -10
-0.38308 -15.4656 0 $ E7 source
-0.38308 -15.4656 10
-0.38308 -15.4656 -10
-0.79869 -15.88121 0
-0.79869 -15.88121 10
-0.79869 -15.88121 -10
-1.12187 -16.20439 0
-1.12187 -16.20439 10
-1.12187 -16.20439 -10
-4.73664 -15.4656 0 $ E8 source
```

```
-4.73664 -15.4656 10
-4.73664 -15.4656 -10
-5.15225 -15.88121 0
-5.15225 -15.88121 10
-5.15225 -15.88121 -10
-5.47543 -16.20439 0
-5.47543 -16.20439 10
-5.47543 -16.20439 -10
-9.0902 -15.4656 0 $ E9 source
-9.0902 -15.4656 10
-9.0902 -15.4656 -10
-9.50581 -15.88121 0
-9.50581 -15.88121 10
-9.50581 -15.88121 -10
-9.82899 -16.20439 0
-9.82899 -16.20439 10
-9.82899 -16.20439 -10
-11.6937 -11.26698 0 $ E10 source
-11.6937 -11.26698 10
-11.6937 -11.26698 -10
-12.10931 -11.68259 0
-12.10931 -11.68259 10
-12.10931 -11.68259 -10
-12.43249 -12.00577 0
-12.43249 -12.00577 10
-12.43249 -12.00577 -10
-13.44376 -7.92434 0 $ E11 source
-13.44376 -7.92434 10
-13.44376 -7.92434 -10
-13.85937 -8.33995 0
-13.85937 -8.33995 10
-13.85937 -8.33995 -10
-14.18255 -8.66313 0
-14.18255 -8.66313 10
-14.18255 -8.66313 -10
-15.62054 -4.15244 0 $ E12 source
-15.62054 -4.15244 10
-15.62054 -4.15244 -10
-16.03615 -4.56805 0
-16.03615 -4.56805 10
-16.03615 -4.56805 -10
-16.35933 -4.89123 0
-16.35933 -4.89123 10
-16.35933 -4.89123 -10
-17.79732 -0.38308 0 $ E13 source
-17.79732 -0.38308 10
-17.79732 -0.38308 -10
-18.21293 -0.79869 0
-18.21293 -0.79869 10
-18.21293 -0.79869 -10
```

```
-18.53611 -1.12187 0
-18.53611 -1.12187 10
-18.53611 -1.12187 -10
-15.62054 4.15244 0 $ E14 source
-15.62054 4.15244 10
-15.62054 4.15244 -10
-16.03615 4.56805 0
-16.03615 4.56805 10
-16.03615 4.56805 -10
-16.35933 4.89123 0
-16.35933 4.89123 10
-16.35933 4.89123 -10
-13.44376 7.92434 0 $ E15 source
-13.44376 7.92434 10
-13.44376 7.92434 -10
-13.85937 8.33995 0
-13.85937 8.33995 10
-13.85937 8.33995 -10
-14.18255 8.66313 0
-14.18255 8.66313 10
-14.18255 8.66313 -10
-11.6937 11.26698 0 $ E16 source
-11.6937 11.26698 10
-11.6937 11.26698 -10
-12.10931 11.68259 0
-12.10931 11.68259 10
-12.10931 11.68259 -10
-12.43249 12.00577 0
-12.43249 12.00577 10
-12.43249 12.00577 -10
-9.0902 15.4656 0 $ E17 source
-9.0902 15.4656 10
-9.0902 15.4656 -10
-9.50581 15.88121 0
-9.50581 15.88121 10
-9.50581 15.88121 -10
-9.82899 16.20439 0
-9.82899 16.20439 10
-9.82899 16.20439 -10
-4.73664 15.4656 0 $ E18 source
-4.73664 15.4656 10
-4.73664 15.4656 -10
-5.15225 15.88121 0
-5.15225 15.88121 10
-5.15225 15.88121 -10
-5.47543 16.20439 0
-5.47543 16.20439 10
-5.47543 16.20439 -10
-0.38308 15.4656 0 $ E19 source
-0.38308 15.4656 10
```

```
-0.38308 15.4656 -10
-0.79869 15.88121 0
-0.79869 15.88121 10
-0.79869 15.88121 -10
-1.12187 16.20439 0
-1.12187 16.20439 10
-1.12187 16.20439 -10
4.73664 15.4656 0 $ E20 source
4.73664 15.4656 10
4.73664 15.4656 -10
5.15225 15.88121 0
5.15225 15.88121 10
5.15225 15.88121 -10
5.47543 16.20439 0
5.47543 16.20439 10
5.47543 16.20439 -10
9.0902 15.4656 0 $ E21 source
9.0902 15.4656 10
9.0902 15.4656 -10
9.50581 15.88121 0
9.50581 15.88121 10
9.50581 15.88121 -10
9.82899 16.20439 0
9.82899 16.20439 10
9.82899 16.20439 -10
11.6937 11.26698 0 $ E22 source
11.6937 11.26698 10
11.6937 11.26698 -10
12.10931 11.68259 0
12.10931 11.68259 10
12.10931 11.68259 -10
12.43249 12.00577 0
12.43249 12.00577 10
12.43249 12.00577 -10
13.44376 7.92434 0 $ E23 source
13.44376 7.92434 10
13.44376 7.92434 -10
13.85937 8.33995 0
13.85937 8.33995 10
13.85937 8.33995 -10
14.18255 8.66313 0
14.18255 8.66313 10
14.18255 8.66313 -10
15.62054 4.15244 0 $ E24 source
15.62054 4.15244 10
15.62054 4.15244 -10
16.03615 4.56805 0
16.03615 4.56805 10
16.03615 4.56805 -10
16.35933 4.89123 0
```

```
        16.35933 4.89123 10
        16.35933 4.89123 -10
        22.15088 -0.38308 0 $ F1 source
        22.15088 -0.38308 10
        22.15088 -0.38308 -10
        22.56649 -0.79869 0
        22.56649 -0.79869 10
        22.56649 -0.79869 -10
        22.88967 -1.12187 0
        22.88967 -1.12187 10
        22.88967 -1.12187 -10
        19.9741 -4.15244 0 $ F2 source
        19.9741 -4.15244 10
        19.9741 -4.15244 -10
        20.38971 -4.56805 0
        20.38971 -4.56805 10
        20.38971 -4.56805 -10
        20.71289 -4.89123 0
        20.71289 -4.89123 10
        20.71289 -4.89123 -10
        17.79732 -7.92434 0 $ F3 source
        17.79732 -7.92434 10
        17.79732 -7.92434 -10
        18.21293 -8.33995 0
        18.21293 -8.33995 10
        18.21293 -8.33995 -10
        18.53611 -8.66313 0
        18.53611 -8.66313 10
        18.53611 -8.66313 -10
        15.62054 -11.6937 0 $ F4 source
        15.62054 -11.6937 10
        15.62054 -11.6937 -10
        16.03615 -12.10931 0
        16.03615 -12.10931 10
        16.03615 -12.10931 -10
        16.35933 -12.43249 0
        16.35933 -12.43249 10
        16.35933 -12.43249 -10
        13.44376 -15.4656 0 $ F5 source
        13.44376 -15.4656 10
        13.44376 -15.4656 -10
        13.85937 -15.88121 0
        13.85937 -15.88121 10
        13.85937 -15.88121 -10
        14.18255 -16.20439 0
        14.18255 -16.20439 10
        14.18255 -16.20439 -10
c        11.26698 -19.23496 0 $ F6 source
c        11.26698 -19.23496 10
c        11.26698 -19.23496 -10
```

```
c       11.68259 -19.65057 0
c       11.68259 -19.65057 10
c       11.68259 -19.65057 -10
c       12.00577 -19.97375 0
c       12.00577 -19.97375 10
c       12.00577 -19.97375 -10
       6.91342 -19.23496 0 $ F7 source
       6.91342 -19.23496 10
       6.91342 -19.23496 -10
       7.32903 -19.65057 0
       7.32903 -19.65057 10
       7.32903 -19.65057 -10
       7.65221 -19.97375 0
       7.65221 -19.97375 10
       7.65221 -19.97375 -10
       2.55986 -19.23496 0 $ F8 source
       2.55986 -19.23496 10
       2.55986 -19.23496 -10
       2.97547 -19.65057 0
       2.97547 -19.65057 10
       2.97547 -19.65057 -10
       3.29865 -19.97375 0
       3.29865 -19.97375 10
       3.29865 -19.97375 -10
       -2.55986 -19.23496 0 $ F9 source
       -2.55986 -19.23496 10
       -2.55986 -19.23496 -10
       -2.97547 -19.65057 0
       -2.97547 -19.65057 10
       -2.97547 -19.65057 -10
       -3.29865 -19.97375 0
       -3.29865 -19.97375 10
       -3.29865 -19.97375 -10
       -6.91342 -19.23496 0 $ F10 source
       -6.91342 -19.23496 10
       -6.91342 -19.23496 -10
       -7.32903 -19.65057 0
       -7.32903 -19.65057 10
       -7.32903 -19.65057 -10
       -7.65221 -19.97375 0
       -7.65221 -19.97375 10
       -7.65221 -19.97375 -10
c       -11.26698 -19.23496 0 $ F11 source
c       -11.26698 -19.23496 10
c       -11.26698 -19.23496 -10
c       -11.68259 -19.65057 0
c       -11.68259 -19.65057 10
c       -11.68259 -19.65057 -10
c       -12.00577 -19.97375 0
c       -12.00577 -19.97375 10
```

```
c       -12.00577 -19.97375 -10
       -13.44376 -15.4656 0 $ F12 source
       -13.44376 -15.4656 10
       -13.44376 -15.4656 -10
       -13.85937 -15.88121 0
       -13.85937 -15.88121 10
       -13.85937 -15.88121 -10
       -14.18255 -16.20439 0
       -14.18255 -16.20439 10
       -14.18255 -16.20439 -10
       -15.62054 -11.6937 0 $ F13 source
       -15.62054 -11.6937 10
       -15.62054 -11.6937 -10
       -16.03615 -12.10931 0
       -16.03615 -12.10931 10
       -16.03615 -12.10931 -10
       -16.35933 -12.43249 0
       -16.35933 -12.43249 10
       -16.35933 -12.43249 -10
       -17.79732 -7.92434 0 $ F14 source
       -17.79732 -7.92434 10
       -17.79732 -7.92434 -10
       -18.21293 -8.33995 0
       -18.21293 -8.33995 10
       -18.21293 -8.33995 -10
       -18.53611 -8.66313 0
       -18.53611 -8.66313 10
       -18.53611 -8.66313 -10
       -19.9741 -4.15244 0 $ F15 source
       -19.9741 -4.15244 10
       -19.9741 -4.15244 -10
       -20.38971 -4.56805 0
       -20.38971 -4.56805 10
       -20.38971 -4.56805 -10
       -20.71289 -4.89123 0
       -20.71289 -4.89123 10
       -20.71289 -4.89123 -10
       -22.15088 -0.38308 0 $ F16 source
       -22.15088 -0.38308 10
       -22.15088 -0.38308 -10
       -22.56649 -0.79869 0
       -22.56649 -0.79869 10
       -22.56649 -0.79869 -10
       -22.88967 -1.12187 0
       -22.88967 -1.12187 10
       -22.88967 -1.12187 -10
       -19.9741 4.15244 0 $ F17 source
       -19.9741 4.15244 10
       -19.9741 4.15244 -10
       -20.38971 4.56805 0
```

```
-20.38971 4.56805 10
-20.38971 4.56805 -10
-20.71289 4.89123 0
-20.71289 4.89123 10
-20.71289 4.89123 -10
-17.79732 7.92434 0 $ F18 source
-17.79732 7.92434 10
-17.79732 7.92434 -10
-18.21293 8.33995 0
-18.21293 8.33995 10
-18.21293 8.33995 -10
-18.53611 8.66313 0
-18.53611 8.66313 10
-18.53611 8.66313 -10
-15.62054 11.6937 0 $ F19 source
-15.62054 11.6937 10
-15.62054 11.6937 -10
-16.03615 12.10931 0
-16.03615 12.10931 10
-16.03615 12.10931 -10
-16.35933 12.43249 0
-16.35933 12.43249 10
-16.35933 12.43249 -10
-13.44376 15.4656 0 $ F20 source
-13.44376 15.4656 10
-13.44376 15.4656 -10
-13.85937 15.88121 0
-13.85937 15.88121 10
-13.85937 15.88121 -10
-14.18255 16.20439 0
-14.18255 16.20439 10
-14.18255 16.20439 -10
-11.26698 19.23496 0 $ F21 source
-11.26698 19.23496 10
-11.26698 19.23496 -10
-11.68259 19.65057 0
-11.68259 19.65057 10
-11.68259 19.65057 -10
-12.00577 19.97375 0
-12.00577 19.97375 10
-12.00577 19.97375 -10
-6.91342 19.23496 0 $ F22 source
-6.91342 19.23496 10
-6.91342 19.23496 -10
-7.32903 19.65057 0
-7.32903 19.65057 10
-7.32903 19.65057 -10
-7.65221 19.97375 0
-7.65221 19.97375 10
-7.65221 19.97375 -10
```

```
-2.55986 19.23496 0 $ F23 source
-2.55986 19.23496 10
-2.55986 19.23496 -10
-2.97547 19.65057 0
-2.97547 19.65057 10
-2.97547 19.65057 -10
-3.29865 19.97375 0
-3.29865 19.97375 10
-3.29865 19.97375 -10
2.55986 19.23496 0 $ F24 source
2.55986 19.23496 10
2.55986 19.23496 -10
2.97547 19.65057 0
2.97547 19.65057 10
2.97547 19.65057 -10
3.29865 19.97375 0
3.29865 19.97375 10
3.29865 19.97375 -10
6.91342 19.23496 0 $ F25 source
6.91342 19.23496 10
6.91342 19.23496 -10
7.32903 19.65057 0
7.32903 19.65057 10
7.32903 19.65057 -10
7.65221 19.97375 0
7.65221 19.97375 10
7.65221 19.97375 -10
11.26698 19.23496 0 $ F26 source
11.26698 19.23496 10
11.26698 19.23496 -10
11.68259 19.65057 0
11.68259 19.65057 10
11.68259 19.65057 -10
12.00577 19.97375 0
12.00577 19.97375 10
12.00577 19.97375 -10
13.44376 15.4656 0 $ F27 source
13.44376 15.4656 10
13.44376 15.4656 -10
13.85937 15.88121 0
13.85937 15.88121 10
13.85937 15.88121 -10
14.18255 16.20439 0
14.18255 16.20439 10
14.18255 16.20439 -10
15.62054 11.6937 0 $ F28 source
15.62054 11.6937 10
15.62054 11.6937 -10
16.03615 12.10931 0
16.03615 12.10931 10
```

```
       16.03615 12.10931 -10
       16.35933 12.43249 0
       16.35933 12.43249 10
       16.35933 12.43249 -10
       17.79732 7.92434 0 $ F29 source
       17.79732 7.92434 10
       17.79732 7.92434 -10
       18.21293 8.33995 0
       18.21293 8.33995 10
       18.21293 8.33995 -10
       18.53611 8.66313 0
       18.53611 8.66313 10
       18.53611 8.66313 -10
       19.9741 4.15244 0 $ F30 source
       19.9741 4.15244 10
       19.9741 4.15244 -10
       20.38971 4.56805 0
       20.38971 4.56805 10
       20.38971 4.56805 -10
       20.71289 4.89123 0
       20.71289 4.89123 10
       20.71289 4.89123 -10
f4:n 20011
e4 1.00000E-11
     5.00000E-09
     1.00000E-08
     1.50000E-08
     2.00000E-08
     2.50000E-08
     3.00000E-08
     3.50000E-08
     4.20000E-08
     5.00000E-08
     5.80000E-08
     6.70000E-08
     8.00000E-08
     1.00000E-07
     1.52000E-07
     2.51000E-07
     4.14000E-07
     6.83000E-07
     1.12500E-06
     1.85500E-06
     3.05900E-06
     5.04300E-06
     8.31500E-06
     1.37100E-05
     2.26000E-05
     3.72700E-05
     6.14400E-05
```

```
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      1.67000E-04
      2.75400E-04
      4.54000E-04
      7.48500E-04
      1.23400E-03
      2.03500E-03
      2.40400E-03
      2.84000E-03
      3.35500E-03
      5.53100E-03
      9.11900E-03
      1.50300E-02
      1.98900E-02
      2.55400E-02
      4.08700E-02
      6.73800E-02
      1.11100E-01
      1.83200E-01
      3.02000E-01
      3.88700E-01
      4.97900E-01
      6.39279E-01
      8.20850E-01
      1.10803E+00
      1.35335E+00
      1.73774E+00
      2.23130E+00
      2.86505E+00
      3.67879E+00
      4.96585E+00
      6.06500E+00
      1.00000E+01
      1.49182E+01
      1.69046E+01
      2.00000E+01
      2.50000E+01
f14:n 120011
e14 1.00000E-11
      5.00000E-09
      1.00000E-08
      1.50000E-08
      2.00000E-08
      2.50000E-08
      3.00000E-08
      3.50000E-08
      4.20000E-08
      5.00000E-08
      5.80000E-08
      6.70000E-08
```

8.00000E-08
1.00000E-07
1.52000E-07
2.51000E-07
4.14000E-07
6.83000E-07
1.12500E-06
1.85500E-06
3.05900E-06
5.04300E-06
8.31500E-06
1.37100E-05
2.26000E-05
3.72700E-05
6.14400E-05
1.01300E-04
1.67000E-04
2.75400E-04
4.54000E-04
7.48500E-04
1.23400E-03
2.03500E-03
2.40400E-03
2.84000E-03
3.35500E-03
5.53100E-03
9.11900E-03
1.50300E-02
1.98900E-02
2.55400E-02
4.08700E-02
6.73800E-02
1.11100E-01
1.83200E-01
3.02000E-01
3.88700E-01
4.97900E-01
6.39279E-01
8.20850E-01
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1.35335E+00
1.73774E+00
2.23130E+00
2.86505E+00
3.67879E+00
4.96585E+00
6.06500E+00
1.00000E+01
1.49182E+01
1.69046E+01

```
      2.00000E+01
      2.50000E+01
f24:n 130011
e24 1.00000E-11
      5.00000E-09
      1.00000E-08
      1.50000E-08
      2.00000E-08
      2.50000E-08
      3.00000E-08
      3.50000E-08
      4.20000E-08
      5.00000E-08
      5.80000E-08
      6.70000E-08
      8.00000E-08
      1.00000E-07
      1.52000E-07
      2.51000E-07
      4.14000E-07
      6.83000E-07
      1.12500E-06
      1.85500E-06
      3.05900E-06
      5.04300E-06
      8.31500E-06
      1.37100E-05
      2.26000E-05
      3.72700E-05
      6.14400E-05
      1.01300E-04
      1.67000E-04
      2.75400E-04
      4.54000E-04
      7.48500E-04
      1.23400E-03
      2.03500E-03
      2.40400E-03
      2.84000E-03
      3.35500E-03
      5.53100E-03
      9.11900E-03
      1.50300E-02
      1.98900E-02
      2.55400E-02
      4.08700E-02
      6.73800E-02
      1.11100E-01
      1.83200E-01
      3.02000E-01
```

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     3.88700E-01
     4.97900E-01
     6.39279E-01
     8.20850E-01
     1.10803E+00
     1.35335E+00
     1.73774E+00
     2.23130E+00
     2.86505E+00
     3.67879E+00
     4.96585E+00
     6.06500E+00
     1.00000E+01
     1.49182E+01
     1.69046E+01
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     2.50000E+01
mode n
kcode 500000 1.0 25 100
imp:n 0 1 1386r
rand seed=1
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Vita

Mike Pierce currently serves as a lieutenant commander in the U.S. Navy Judge Advocate General's Corps (JAG Corps). After graduating from the United States Naval Academy with a B.S. in Mechanical Engineering, with distinction, Mike served as a nuclear submarine officer onboard the USS Alaska and USS West Virginia before being assigned as the S6G Fleet Engineer at Naval Reactors in Washington, D.C. While stationed at Naval Reactors, Mike was selected to participate in the Navy's Law Education Program. He then attended Georgetown University Law School where he graduated magna cum laude in 2015. Since graduating from law school, he has held various assignments in the Navy JAG Corps in Norfolk, VA, and Washington, D.C., and he currently serves as the Military Justice Action Branch Head at the Office of the Judge Advocate General Criminal Law Division (Code 20).

Mike lives in Alexandria, VA, with his wife, Jadzia, and their two Labrador retrievers, Gunner and Austin.

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